

# A STUDY OF PAYLOAD SPECIALIST STATION MONITOR SIZE CONSTRAINTS

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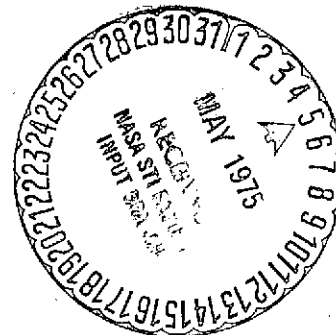
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## 1.0 EXECUTIVE SUMMARY

The study reported here dealt with constraints on the CRT display size for the Shuttle Orbiter aft cabin. The viewing requirements placed on these monitors were assumed to involve two cases:

- . Display of imaged scenes providing visual feedback during payload operations.
- . Display of alphanumeric characters such as numerical data, printed instructions, etc.

To determine viewing requirements for imaged scenes, previously collected data on target detection/resolution, target recognition, and range rate detection by human observers were utilized. These data were sufficient to establish equations giving:

- . Required image size for target detection as a function of range, field-of-view, target size, signal-to-noise ratio, and bandwidth.
- . Required image size for target recognition as a function of range, field-of-view, target size, signal-to-noise ratio, and bandwidth.
- . Required rate of change of image size for range rate detection as a function of range, field-of-view, target size, range rate, signal-to-noise ratio, and bandwidth.

Field-of-view and acuity requirements for a variety of payload operations were obtained. These data established the necessary detection capability in terms of range-to-target size ratios. The data on operator detection capability were used to establish the monitor size necessary to meet the acuity requirements.

It was assumed that a zoom optics camera would be employed having a maximum diagonal field-of-view of 55 degrees and a minimum diagonal field-of-view of 7 degrees. Further assumptions included a minimum signal-to-noise ratio of 32 db and a minimum bandwidth of 4.5 MHz for

the STS video system. Under these conditions, a monitor size of 20 x 20 cm (8 x 8 in.) was found to satisfy all the detection requirements studied here.

To determine required recognition sizes for displayed alphanumeric characters, an empirical test was conducted. The results of this test were used to determine the number of characters which could be simultaneously displayed based on the recognition size requirements using the proposed monitor size.

Based on the obtained data, a CRT size of 20 x 20 cm. (8 x 8 in.) is recommended. A portion of this display area 15 x 20 cm. (6 x 8 in.) would be used for displaying imaged scenes having a standard aspect ratio of 3:4. The remaining 5 x 20 cm. (2 x 8 in.) display area would be used for alphanumeric characters pertaining to a displayed scene. The entire display would be used for the character alone mode. The recommended monitor size was found to be consistent with the following capabilities:

- . Detection of targets subtending .6 m. rad. at the camera lens using a 7 degree field of view and 71 cm. (28 in.) viewing distance.
- . Recognition of targets subtending 4.0 m. rad. at the camera lens using a 7 degree field of view and 71 cm. (28 in.) viewing distance.
- . Detection of range rate of .06 ft/sec (.02 m/sec) of a 1m. (3.3 ft.) object at a range of 6.1 m. (20 ft.) using a 7 degree field of view and 71 cm. (28 in.) viewing distance.
- . Recognition of arrays of 670 characters with standard vertical spacing or 930 characters with minimum spacing at a viewing distance of 71 cm. (28 in.)

Sufficient data are included in the report to permit re-evaluation of CRT size requirements if video system parameters change or if more stringent STS viewing requirements become known as payload definition proceeds.

## 2.0 Introduction

The Space Shuttle Transportation System (STS) is presently envisioned as operating in either of two modes - payload deployment/support and Spacelab. The Spacelab mode includes pallet only and pallet plus pressurized module missions. The accommodation of payload deployment and pallet only missions is currently based on control and observation of various payloads from one or more stations in the aft cabin of the Shuttle Orbiter. The Payload Station (PS) will contain controls and displays which are commonly required by a range of payloads as well as those which are payload peculiar. The basic approach, however, is to utilize standard panel elements to the greatest extent possible. This approach is consistent with the goals of providing low cost, standardized interfaces, and minimized turn-around or mission preparation time.

The displays associated with the PS will generally refer to experiment operations involving pallet mounted apparatus, deployment of attached apparatus (i.e. telescopes, booms) and deployment and control of free-flying payloads such as sub-satellites. Deployment/support missions will involve displays required for deployment, control and retrieval of a range of satellites and free-flying vehicles including teleoperator, and space tug. In many of these cases, the deployment mechanism will be the Shuttle Remote Manipulator System (RMS). Other deployment devices will be payload dedicated and designed for special purposes of particular experiments.

The information to be displayed at the PS to permit the necessary control and observation activities will thus be both alphanumeric and pictorial. The alphanumeric information will include payload/STS generated data such as experiment sensor readouts, support data, instrument check data, free flying vehicle sensor returns, etc. A second class of alphanumeric information will

be ground generated and will include parameter values, checklists, procedural information and other classes of information uplinked to support on-orbit operations. Such data could include schematics, diagrams, flow charts, and would thus be graphic in format but with associated alphanumerics.

The currently planned method of display of alphanumerics includes dedicated indicators and meters. However, much of the display load is to be allocated to the CRT display at the PS. The nominal mode of display would utilize a standardized character generator to present alphanumerics via the CRT. In off-nominal cases, however, the uplinked data might be generated via camera viewing of hard copy.

The pictorial data to be displayed may arise from cameras mounted in the bay to provide general viewing of pallet mounted payloads, RMS dedicated cameras, or cameras mounted in free flying payloads including satellites (with internal or external cameras), space tug, and teleoperator, and cameras located within pallet mounted experiments in conjunction with telescopes.

The Orbiter aft cabin stations will thus be required to provide an extensive display capability. Furthermore, the current intent is to utilize common displays and to minimize the need for payload peculiar displays in the aft cabin. This approach requires that the CRT displays be capable of accommodating a majority of payload viewing requirements.

Accordingly, the basic display at the PS panel will be one or more multifunction CRT's. By suitable interface design, the multifunction CRT can display a variety of pictorial and alphanumeric information. This approach is planned to minimize the necessity for dedicated indicators, meters and other visual displays and still provide a display capability able to accommodate a wide range of payload display requirements. The classes of data currently envisioned for display via multifunction CRT('s) may be summarized as follows:

- . Television rasters displaying remote scenes. These include returns from cameras in the bay or cameras mounted on remote manipulator systems such as RMS and FFTO.
- . Pictorial information such as graphs, charts, or diagrams uplinked from the ground. The necessary information would be imaged by a television camera viewing hard copy.
- . Alphanumeric character strings which present readouts of relevant mission parameters, caution and warning, checklists, written procedures, etc. These represent nominal preplanned information categories. The character strings would presumably be generated electronically.
- . Alphanumeric character strings required by contingency situations. These categories would not be preplanned but would be uplinked from printed materials via a television camera. This mode would not be optimal but might be required in various off-nominal situations.

The problem addressed in this effort is that the requirement to display the types of information listed above tends to drive up the CRT size. The panel space, however, is tightly constrained by the volume available in the aft cabin. Since panel space and volume are limited, the CRT size cannot be increased arbitrarily. Since a minimum size of the displayed image (character, scene feature, etc.) is required for recognition, the information content must be traded against CRT size. The current effort was performed to establish the necessary data to perform this trade-off. These data and the rationale for the trade-off were developed analytically and empirically.

The approach employed in the current effort was to establish required characteristics of the displayed images in the various information categories for correct recognition by the payload specialist. These characteristics include image size, contrast, etc. and depend on system bandwidth, signal-to-noise ratio, gamma, and other factors. These considerations provide constraints on monitor size since monitor size enters into the relationships between target

characteristics and displayed image characteristics. These constraints were determined parametrically for the cases of pictorial and character displays via analysis of display size impacts on the operator's visual performance with respect to both types of displays. Finally these data were used to trade-off display size versus amount of information available from the display.

### 3.0 APPROACH

The approach employed consisted of the steps depicted in Figure 3-1. The initial phase of the effort was separated into two major flow paths devoted to pictorial data and alphanumeric data respectively. The steps carried out with respect to pictorial data included identification of visual requirements, assessment of relevant data on operator visual capabilities, analytic determination of required image characteristics based on the first two steps, and parametric evaluation of the impacts of display size on the satisfaction of visual requirements.

#### 3.1 Analysis of Pictorial Display Requirements

The initial step in dealing with monitor size constraints was the identification of visual requirements imposed by the types of visual tasks to be performed. This effort was based on documentation relating to operator visual tasks in STS operations (Refs. 1, 2, 3, 4, 5, 6, 7). The visual tasks identified as primarily impacting performance in the case of pictorial displays were:

- . Minimum object size detection/resolution
- . Pattern/shape recognition/discrimination
- . Detection of range rate

The displayed image characteristics which serve as cues to permit the above visual tasks to be performed were identified based on relevant studies of operator performance in visual tasks (Refs. 2, 6, and 8). A detailed discussion of the equations relating video system parameters to image characteristics and the constraints imposed on image characteristics are discussed in Section 4.0.

The above analyses resulted in payload visual requirements such as the resolution of alignment errors during manipulations in the shuttle bay. The

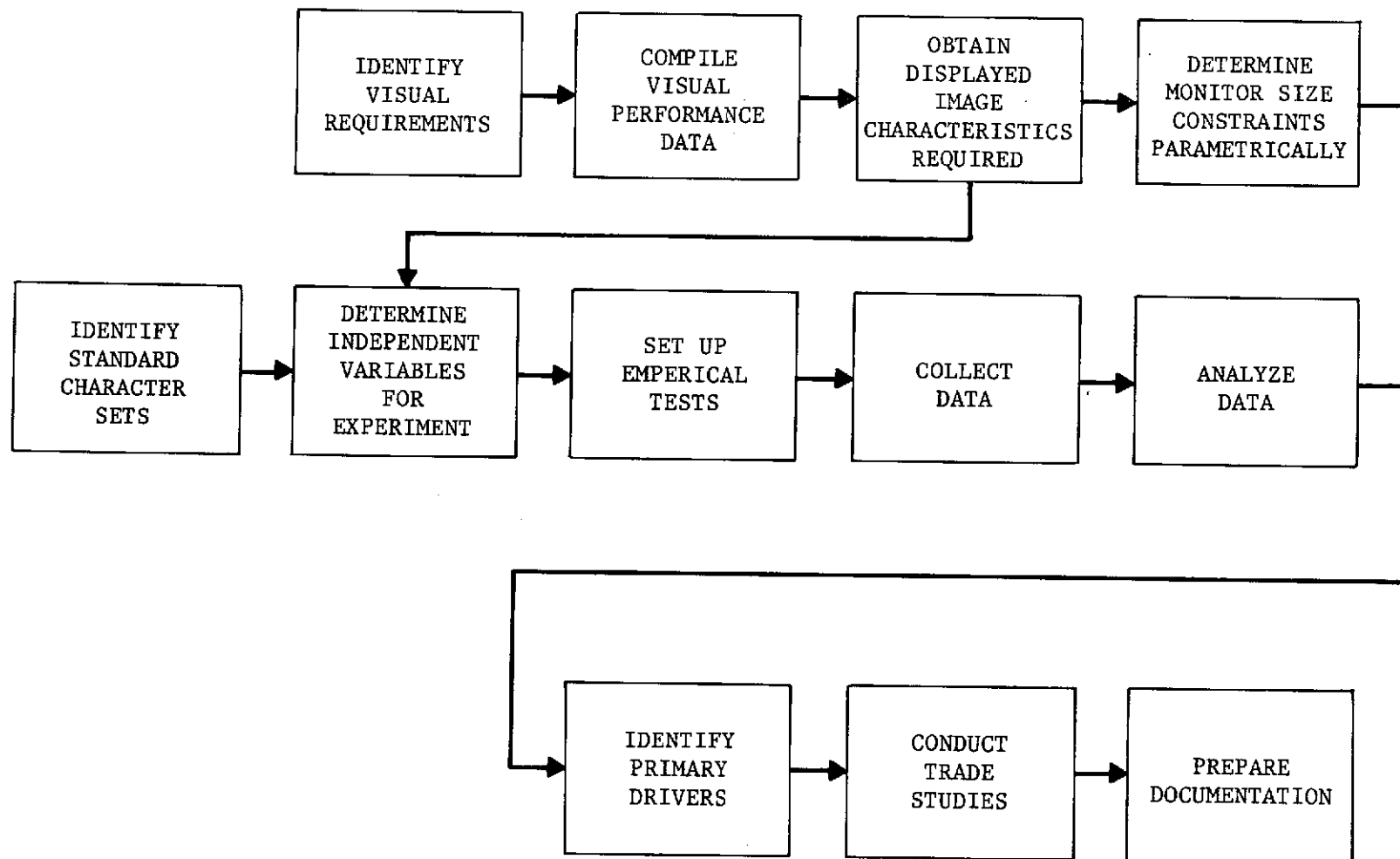


Figure 3-1. PROGRAM FLOW

relationships between video system parameters and display image characteristics were then determined. Constraints on image characteristics such as display target image dimensions based on operator visual capabilities were then developed. This permitted parametric analysis of the impact of monitor size on the ability of the video system and operator to satisfy the initial payload visual requirements.

### 3.2 Analysis of Alphanumeric Display Requirements

The effort devoted to pictorial requirements was carried out via analytical studies using published requirements data and operator visual performance data. The effort devoted to alphanumeric presentation, however, required empirical investigation of character recognition performance via television. This was due to the fact that standard sources of operator performance data (Refs. 9, 10, 11 and 12) did not contain the necessary crew systems. The available data were related to direct vision character recognition which does not take into account resolution and other impacting factors of video systems.

Accordingly, the steps carried out for the case of alphanumeric displays included the design and conduct of empirical tests of character recognition performance. These tests were conducted using the facilities of the Teleoperator Visual Systems Laboratory at MSFC. The initial step was the identification of standard character sets planned for use with the STS. These were specified based on Ref. 10 which is the baseline specification for Spacecraft crew systems. The character sets presently available from existing character generators at MSFC were identified for comparison with the standard character set. The empirical tests of character recognition performance were designed to quantify required

character size and spacing as functions of video system parameters known from previous research to impact pattern recognition. The details of these tests are presented in Sections 5, 6, and 7. The data analyses performed following data collection were designed to incorporate character recognition and character string comprehension into the pictorial display tasks and parameters discussed previously.

### 3.3 Identification of Display Size Constraints

The outputs of the efforts previously described were used to carry out the third major effort. The parametric relationships developed for the identified visual tasks and task performance requirements served to identify the primary drivers in the determination of display size. The available data on detection requirements for STS payload operations were used to determine display size based on worst case requirements. The monitor size selection was thus based primarily on detection requirements. The capabilities of this monitor size for target recognition, range rate detection, and character recognition were projected and evaluated with respect to expected requirements. Finally, support data and analyses conducted were documented to permit revision of monitor size requirements if more stringent viewing requirements become apparent as payload definition proceeds.

#### 4.0 Monitor Size Constraints Based on Imaged Scenes

As discussed previously, the viewing requirements placed on the CRT display at the PSS may be conveniently divided into two general types--those based on imaging remote scenes (i.e. pictorial) and those associated with displays of alphanumeric characters. The derivation of display size constraints from imaged scene requirements depends on several established relationships between video system characteristics and the visual capabilities of the operator or observer.

The classes of visual tasks identified as the primary determinants of adequate viewing in the STS context include:

- . Minimum object size detection/resolution
- . Pattern/shape recognition/discrimination
- . Detection of range rate

The present section contains the results of steps 2 through 4 of Figure 3-1. These steps yielded a set of parametric relationships between visual requirements and video system characteristics.

#### 4.1 Minimum Object Size Detection/Resolution

Detection and resolution as used here refer to the operator's ability to discern fine detail in the imaged scene during control or observation via a television system. Detection refers to correct discrimination between a field containing a target object and a blank field. Acquisition of the BES satellite at initial rendezvous range is an example of detection. Resolution is typified by edge or gap detection where the long dimension is well above threshold but the gap width is narrow in relation to its length.

Both resolution and detection tasks are dependent on displayed image size and video resolution. The relationship between image size and parameters

of the video system is given by:

$$I = \frac{M \cdot T}{2 R \tan\left(\frac{\Omega}{2}\right)} \quad 4-1$$

where: I = image dimension  
M = monitor dimension  
T = target dimension  
R = target-to-camera range  
 $\Omega$  = angular field-of-view dimension

The monitor (M) and the angular field-of-view ( $\Omega$ ) may be horizontal, vertical, or diagonal measures but they must correspond. That is, if eq. 4-1 is applied to the diagonal dimension, the diagonal field-of-view measure must also be used.

The image size (I) may be used to specify a detection threshold value only if viewing distance between the monitor and the eye is fixed. To allow variable viewing distance, the visual angle may be employed. Visual angle is given by:

$$\lambda \simeq \frac{I}{L} \quad 4-2$$

where:

$\lambda$  = visual angle (radians)  
L = viewing distance

Eq. 4-2 uses the small angle approximation since visual angle thresholds are usually on the order of a few arc minutes. For direct vision, 20-20 visual acuity is equivalent to detection of objects having a visual angle of one arc minute. This figure cannot be directly applied to television viewing, however, because the discrete scan lines and bandwidth limit system resolution. The vertical resolution of a television system is measured by the active scan lines. A 525 line system yields about 340 active lines due to lines lost in the retrace and the Kell effect. Horizontal resolution is measured in terms of lines resolvable in a standard test chart. Thus horizontal resolution is specified

by the resolution visual task. However, a frequently used approximation is that the total number of horizontal elements in the raster is 80 per bandwidth in MHz. Assuming a 4.5 MHz bandwidth for the video system in question, this yields a horizontal resolution of 360 lines per raster width. The system resolution factors impose a limit on eq. 4-2 which if taken literally, implies that an arbitrarily small image can produce an arbitrarily large visual angle.

To obtain a constraint on the system parameters of eq. 4-1 and 4-2 subject to operator visual capability, empirical data concerning detection performance are required. A study of visual angle required for detection of a gap between two target plates has been reported by Kirkpatrick, Malone, and Shields, (Ref 2). A complete description of this test is included as Appendix A of the present report. The primary fixed parameters of the test procedure for the present purpose include the following parameters:

- . Task board albedo of .4 and target plate albedo of .3.  
The absolute contrast ratio between the target plates and the surround was therefore .25. The contrast ratio between the gap and the plates was .33.
- . Standard video camera system having 525 nominal rating.  
Therefore, the display presented approximately 335 actual lines.

The variable parameters studied included:

- . Transmission Mode
  - Analog
  - Digital-4 bit
- . Analog Bandwidth
  - 4.5 MHz
  - 1.0 MHz
- . Signal-to-Noise Ratio
  - Ratio of peak white signal voltage to RMS noise of
  - 32 db
  - 21 db
  - 15 db

The fixed parameters of the test were such that the data are considered applicable to 525 line systems. Contrast was kept at relatively low levels as noted. The data may thus be considered a lower bound on operator detection capability for cases involving contrast levels greater than those stated.

The data on visual angle distributions at gap detection are presented in Figure 1 of Appendix A. For the present analysis, the assumption will be made that the signal-to-noise ratio for the CRT display is maintained at 32 db. The variation in transmission mode and bandwidth was not found to significantly influence detection performance at this level of signal-to-noise ratio. Based on the test data, a visual angle of six arc minutes was found to yield a detection probability of .99. Assuming that a six arc minute visual angle is required for minimum object size detection and resolution, equation 4-2 may be set equal to six arc minutes yielding:

$$.00175 \text{ rad} = \frac{I}{L} \quad 4-4$$

$$I = .00175 L \quad 4-5$$

Incorporating eqs. 4-1 and 4-5:

$$.00175L = \frac{M \cdot T}{2 R \tan \left( \frac{\Omega}{2} \right)} \quad 4-6$$

or, rearranging eq. 4-6:

$$\frac{M}{L} = .00175 \frac{R}{T} 2 \tan \left[ \frac{(\Omega)}{2} \right] \quad 4-7$$

Equation 4-7 expresses the ratio of monitor dimension to viewing distance as a product of a constant, the resolution ratio of range to target size, and the tangent of the half field. The tangent expression in eq. 4-7, however, may be expressed in terms of field of view width and range. These variables are more directly related to viewing requirements than is the angular field of view dimension.

It is evident that:

$$2 \tan \left( \frac{\Omega}{2} \right) = \frac{W_r}{R} \quad 4-8$$

where  $W_r$  is the field of view width subtended by the field of view angle at range  $R$ .

Therefore:

$$\frac{M}{L} = \frac{.00175 \cdot R \cdot W_r}{T \cdot R} \quad 4-9$$

Eq. 4-9 expresses the relationship between viewing parameters necessary for the image of the target dimension  $T$  to be detectable on the display with probability .99 using a S/N ratio of 32 db or better. The numerical constant is derived from the data of Appendix A. Reduction in S/N ratio, bandwidth, etc. would necessitate substitution of a different constant. This constant would be the tangent of the required visual angle based on Figure 1 of Appendix A. Eq. 4-9 expresses constraints on monitor size depending on resolution and viewing coverage requirements. Eq. 4-9 is plotted parametrically in Figure 4-1 showing the ratio of monitor width to viewing distance as a function of the resolution ratio with the coverage ratio as a curve parameter. The vertical scales show monitor width for various viewing distances from 50 cm (19.7 in.) to 80 cm (31.5 in.). The special case of 71.12 cm (28 in.) represents the viewing distance assumed by NASA standard 512 (ref. 10). This viewing distance is typical of that obtained for an operator seated at a panel.

To illustrate the use of Figure 4-1, consider a resolution ratio of 500 to 1. This would permit resolution of a one meter target at 500 meters (acquisition of satellites) or resolution of a one centimeter target at five meters (inspection of payload in bay). If the coverage requirement were .4 times the range (coverage of 4 meters at 10 meter range), the ratio between monitor width and viewing distance would have to be .35. This would yield a monitor width

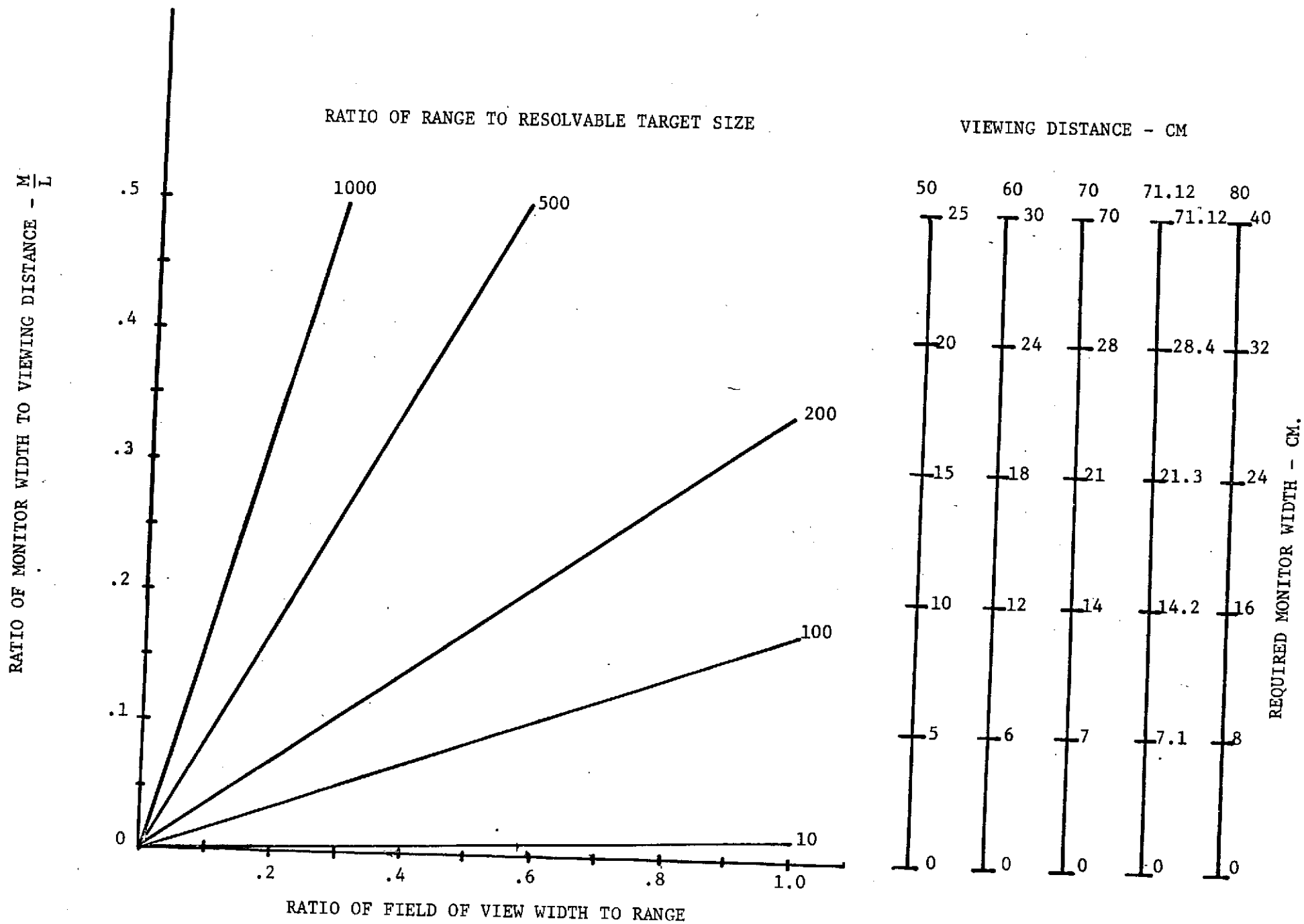


FIGURE 4-1

of 17.5 cm (6.9 in) for a 50 cm (19.7 in.) viewing distance or a width of 24.9 cm. (9.8 in) at the standard viewing distance of 71.12 cm (28 in).

Eq. 4-9 and the results plotted in Figure 4-1 ignore two factors. These are the system resolution factors and the fact that the video system involved in the PSS is likely to contain a zoom capability. If the coverage requirement and the minimum resolution requirement are not simultaneously placed on the video system, the maximum coverage for the high magnification zoom setting may be reduced relative to the wide angle zoom setting by a factor equal to the zoom range. This parameter is equal to at least 5.0 for available off-the-shelf video systems.

As noted previously, eq. 4-9 ( and consequently Figure 4-1) ignores system resolution factors. If viewing distance were reduced below the values shown in Figure 4-1, minimum detectable target size could be reduced somewhat but would eventually be limited by system resolution. To illustrate this effect, eq. 4-9 was solved for the ratio of range to target dimension as a function of the ratio of monitor size (diagonal) to viewing distance. These data were calculated for two fields of view-7 and 55 degrees (diagonal) which are the limits of the zoom optics for the NASA/Lockheed camera. This camera is presently space qualified and was assumed to represent the type of camera which will be utilized in STS video systems. Figure 4-2 shows these data. Resolution capability may be seen to increase linearly up to fixed limits imposed by system horizontal and vertical resolution. The latter factor thus impose an upper limit on the benefits of increasing monitor size or decreasing viewing distance. The limits shown in Figure 4-2 assume one line or resolution element must pass through the target image for detection based on the assumption that the absolute minimum number of lines or resolution elements for detection is one.

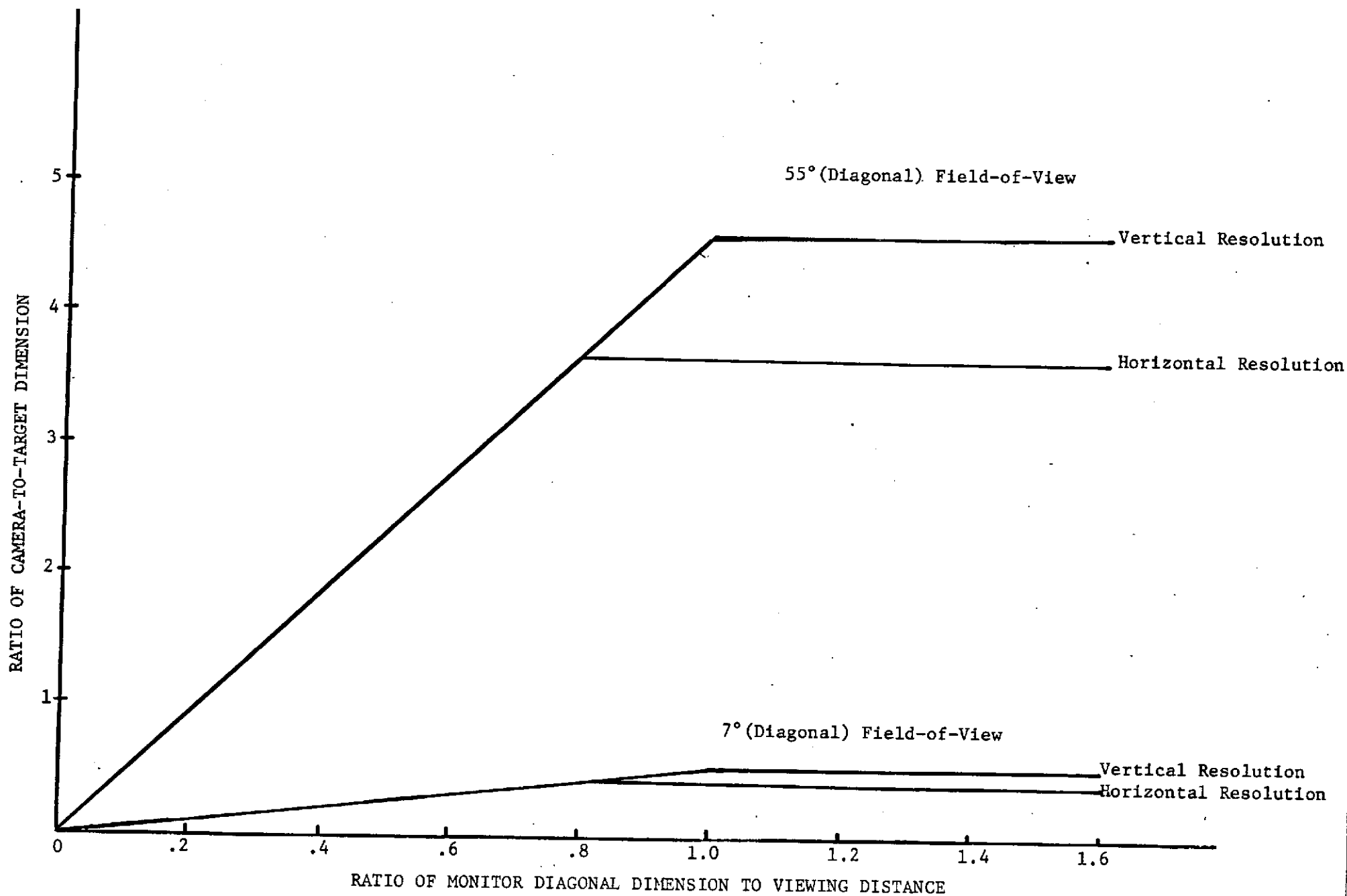


FIGURE 4-2

## 4.2 Pattern Recognition

The previous section has addressed the problem of object detection--the ability to discern the presence of an object in the field of view. Pattern recognition is the ability to recognize or name the object in question and to discriminate between similar objects. Since objects are recognized by features or properties, detection of features presumably underlies pattern recognition. This means that the image size/resolution requirements depend on the size and shape of the features to be detected. If detection of a small feature of an object is essential, the detection data of section 4.1 should be applied.

To obtain a general approach to pattern recognition, the image size equation given as eq. 4-1 is applicable. The system resolution constraints also apply. The target dimension  $T$  of eq. 4-1 should be taken to be the minimum dimension of the object in the case of pattern recognition. The primary impact of the difference between detection and recognition is in the magnitude of the 99th percentile visual angle which must be used.

The visual angle required for recognition of geometric forms was investigated in a study included as Appendix B (Ref. 2). The same assumptions will be employed for recognition as were used for detection:

Signal-to-noise ratio	= 32 db
Bandwidth	= 4.5 MHz
Contrast	~ .3

Under these circumstances, a visual angle of about 40 arc min was found to yield a recognition probability of .99 for the most difficult forms. This yields an image size constraint of:

$$I = .01163L \quad 4-10$$

Substitution of eq. 4-10 in eq. 4-1 yields:

$$.01163L = \frac{M \cdot T}{2 R \tan \frac{(\Omega)}{2}} \quad 4-11$$

and:

$$\frac{M}{L} = .01163 \frac{R}{T} 2 \tan \left( \frac{\Omega}{2} \right) \quad 4-12$$

which provides a constraint on the ratio of monitor size to viewing distance for the case of pattern recognition.

Video system resolution also impacts recognition. According to the data of Sleight (Ref. 9 ) about 12 lines must pass through the target for near certain recognition. This limits the increased pattern recognition performance available by reducing the viewing distance. Eq. 4-12 is illustrated in Figure 4-3 which shows the ratio recognition range to target size as a function of the ratio of field-of-view width to range for fixed ratio of monitor width to viewing distance. The upper curve of Figure 4-3 shows the limit placed on recognition by the resolution of a 4.5 MHz bandwidth system. Because of the twelve-to-one ratio of the number of lines through the target required, the effect of system resolution on recognition is more pronounced than that for detection.

These effects may be compared by noting that the number of lines or resolution elements through the target depends on the ratio of displayed image size to monitor size. By eq. 4-1:

$$\frac{I}{M} = \frac{T}{R} \frac{1}{2 \tan \left( \frac{\Omega}{2} \right)} \quad 4-13$$

The number of lines or resolution elements through the target is then the total number of lines or elements in the raster multiplied by the ratio given by eq. 4-13 using the appropriate angular measure. It is necessary to distinguish four cases consisting of the combinations of resolution vs. recognition and horizontal minimum dimension vs. vertical minimum dimension. In any particular case, the appropriate form of the visual angle constraint is given by either

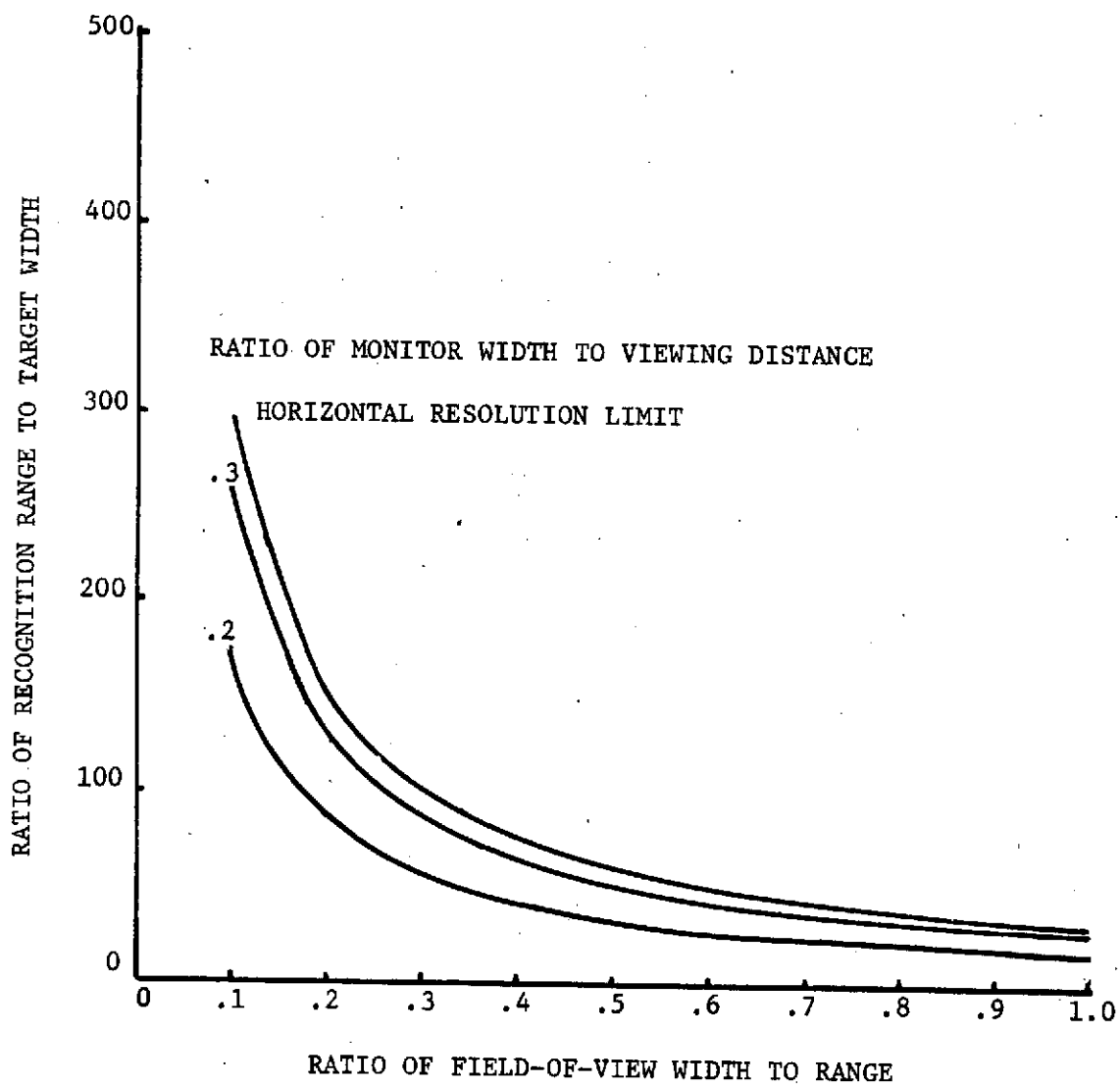


FIGURE 4-3

eq. 4-9 or 4-12. The constraint due to system resolution is given by eq. 4-13. The maximum ratio of recognition range to target size will be given by eq. 4-13 as:

$$\frac{R}{T} = \left[ K \cdot 2 \tan \left( \frac{\Omega}{2} \right) \right]^{-1} \quad 4-14$$

The constant K differs for the four cases. It is the ratio of the number of lines through the target for correct performance to the total number of lines in the raster. For example, in the case of detection of a vertically oriented gap, the gap width must subtend one element and there are assumed to be 360 elements in the raster (4.5 MHz bandwidth) K is therefore equal to .00278. The K factors for the various cases are given in Table 4-1.

Table 4-1 Ratio of Required Lines or Elements Through the Target to Total Lines or Elements in the Raster (K)

<u>Task</u>	<u>ORIENTATION OF CRITICAL TARGET DIMENSION</u>	
	<u>Vertical</u>	<u>Horizontal</u>
Detection/Resolution	$\frac{1}{340} = .00294$	$\frac{1}{360} = .00278$
Recognition	$\frac{12}{340} = .03529$	$\frac{12}{360} = .03333$

Table 4-1 assumes a 525 line system with 4.5 MHz bandwidth.

For one task, the visual angle requirement is given by eq. 4-9 or 4-12. These differ only by a visual angle constant which may be termed  $V_i$  with  $i$  denoting the task. From eq. 4-13, the constraint due to system resolution may be stated as:

$$K_{ij} = \frac{T}{R} \frac{1}{2 \tan \left( \frac{\Omega}{2} \right)} \quad 4-15$$

Eq. 4-16 expresses the maximum range to target size ratio available subject to the system resolution limits. Eqs. 4-9 and 4-12 may be rearranged to yield:

$$\frac{R}{T} = \frac{M}{L} \left[ V_i \cdot 2 \tan \left( \frac{\Omega}{2} \right) \right]^{-1} \quad 4-17$$

Eq. 4-17 expresses the ratio of range to target size as a function of monitor size to viewing distance subject to the constraint  $V_i$  which depends on the task being considered. Eq. 4-17 holds, however, up to the limit imposed by Eq. 4-16. Therefore, the maximum useable ratio of monitor size to viewing distance may be determined by equating eqs. 4-16 and 4-17. The field of view dimension cancels out in each separate case yielding:

$$\frac{M}{L} = \frac{V_i}{K_i j} \quad 4-18$$

The variable  $M$  in eq. 4-18 can refer to either the horizontal or vertical monitor dimension. Eq. 4-18 was solved for the four cases and the results expressed as the ratio of the diagonal monitor dimension to viewing distance for a 3:4 aspect ratio. These values are shown in Table 4-2.

Table 4-2 Maximum Ratio of Monitor Diagonal Dimension to Viewing Distance

<u>Task</u>	<u>Vertical</u>	<u>Horizontal</u>
Detection/Resolution	.992	.787
Recognition	.540	.436

Table 4-2 shows maximum useable ratios of monitor diagonal dimension to viewing distance. Increases in this parameter beyond the tabled values will not generally produce increased detection or recognition performance due to constraints imposed by video system resolution factors.

### 4.3 Detection of Range Rate

A visual estimation task which is strongly impacted by video system parameters is the judgment of whether an object is moving or is stationary along the camera viewing axis. For monoptic television, the primary visual cue is the rate of change of image size. Change in apparent brightness may also provide a cue if the target moves relative to a light source. An investigation of threshold values of image size rate of change was reported by Kirkpatrick et. al. (Ref. 8) and is included here as Appendix C.

An expression for the rate of change of image size may be obtained by differentiating eq. 4-1. This yields:

$$\frac{dI}{dT} = \left[ \frac{-MT}{R \cdot 2 \tan \frac{(\Omega)}{2}} \right] \left[ \frac{dR}{dT} \right] \quad 4-19$$

or:

$$\dot{I} = \frac{-MT \dot{R}}{R \cdot 2 \tan \frac{(\Omega)}{2}} \quad 4-20$$

where  $\dot{I}$  = rate of change of image dimension

$\dot{R}$  = rate of change of object-to-camera range

To generalize eq. 4-20 with respect to viewing distance, the rate of change of visual angle is given by:

$$\dot{\lambda} = \frac{\dot{I}}{L} \quad 4-21$$

As discussed in Appendix C, range rate detection probability was studied for two different ranges. The parameters which were fixed in the study were:

- . Signal-to-noise ratio = 32 db
- . Bandwidth = 4.5 MHz
- . Standard 525 line system
- . High contrast .5,.7 albedo targets on black background
- . Displayed image size well above recognition size.
- . Frame rate = 30 frames/sec.

Under these circumstances, the correct detection probability was found to be .95 for an image size rate of .027 in/sec when a simple reticle was provided. The presence or absence of a reticle was found to influence the detectable rate but reduction in signal to noise ratio (15 db), bandwidth (1MHz) and frame rate (15 frames/second) were found to have little influence on performance.

At the viewing distance employed, the obtained rate of image size corresponds to about .00129 rad/sec or about 4.43 arc min./sec. A general requirement for rate of change of image size is, therefore:

$$\dot{i} = .00129L \quad 4-20$$

Equating eqs. 4-19 and 4-20:

$$.00129L = \frac{MT |\dot{R}|}{R^2 \cdot 2 \tan \left( \frac{\Omega}{2} \right)} \quad 4-21$$

This may be rearranged to yield:

$$\frac{M}{L} = \frac{.00129 R^2 \cdot 2 \tan \left( \frac{\Omega}{2} \right)}{T |\dot{R}|} \quad 4-22$$

The image size for eq. 4-22 to hold is assumed to be equal to the recognition size discussed in section 4.2.

To illustrate eq. 4-22, detectable range rates as a function of range were calculated for two fields of view-10 and 30 degrees and three ratios of monitor diagonal dimension to viewing distance. These data for a target one meter in horizontal dimension are shown in Figure 4-4. Figure 4-4 shows the quadratic relationship between detectable range rate and range.

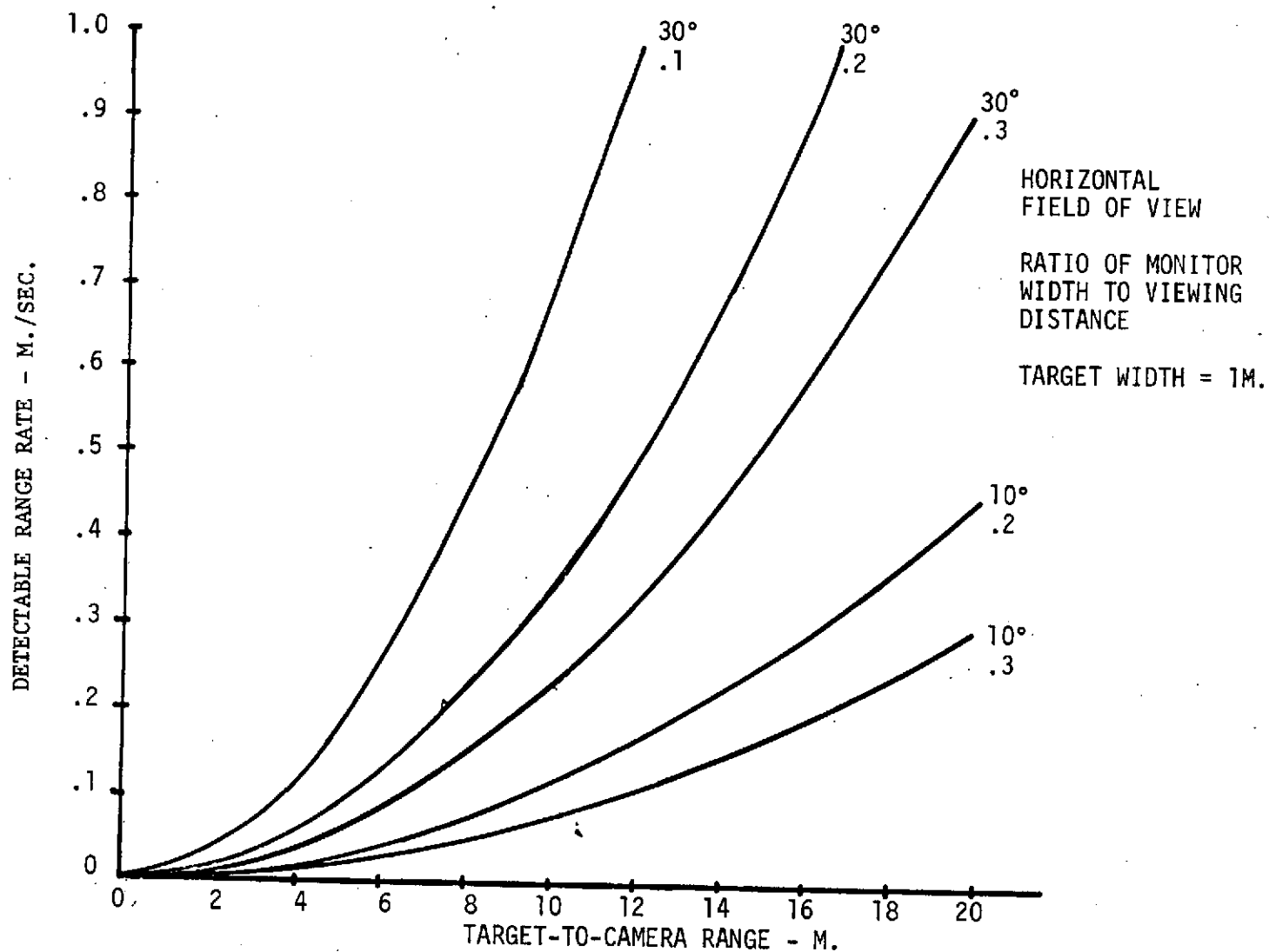


FIGURE 4-4 DETECTABLE RANGE RATE AS A FUNCTION OF RANGE

## 5.0 Monitor Size Constraints Based on Alphanumeric Displays

As discussed in sections 2.0 and 3.0, the second general area of viewing requirements which impacts monitor size is the recognition of alphanumeric characters. In the SST on-orbit operations controlled from the aft cabin, alphanumerics may be displayed as supplementary information during the presentation of imaged scenes. For instance, the Free-Flying Teleoperator displays will include parameters such as range, range rate, attitude rates, manipulator joint torques, etc. To minimize the need for dedicated dials and meters, the present planning calls for display of these data via the CRT display. This introduces an additional impact on video system parameters including monitor size.

A second mode of display envisioned for the aft cabin CRT is character display alone. That is, the CRT would be used to display numerical data, checklists, procedure sequences, etc. In this mode, the imaged scene requirements would not be applicable but the constraints introduced by character recognition would. The total number of characters which must be simultaneously displayed would presumably be the driving factor. Unfortunately, it is difficult to project this factor for STS missions. The approach employed here was to assume the content of a double spaced typed sheet as a baseline requirement.

The parameters governing maximum character number per display area are those previously discussed in section 4.0. A single character is a familiar pattern. It is assumed that character recognition is a case of pattern recognition which requires a certain visual angle for high recognition probability. In addition, the spacing between characters must be sufficient to permit resolution of the adjacent strokes in adjacent characters.

The factors of form recognition and line resolution are therefore applicable. The required visual angle for letter recognition is ordinarily somewhat less than that required for recognition of arbitrary forms (Ref.9). Data on character recognition size are readily available for the case of direct vision (Ref. 9). In view of the tendency for visual performance via television to entail greater visual angles than direct vision, however, these data were not considered applicable to the present problem.

Considering character recognition as a case of the general recognition task discussed in section 4.0, it can be assumed that a certain required character width is necessary for recognition. Width is used since it is the minimum dimension for most alphanumerics. The maximum number of characters per monitor width or height is then dependent on:

$$I \approx \lambda L \quad (5-1)$$

where  $I$  = image dimension  
 $L$  = viewing distance  
 $\lambda$  = required visual angle

Two adjacent characters must be adequately spaced for their adjacent edges to be resolvable. It will be assumed that the resolution constraint of eq. 4-7 can be utilized to ensure separation. Then the minimum vertical extent ( $I_H$ ) occupied by a character is:

$$I_H = L (\lambda_H + .00175) \quad (5-2)$$

where  $\lambda_H$  represents the vertical visual angle. Character width is variable. If  $\lambda_w$  denotes the average visual angle for characters in a set at recognition, the average horizontal extent ( $I_w$ ) is:

$$I_w = L (\lambda_w + .00175) \quad (5-3)$$

The total number of characters which will fill the monitor vertically is:

$$N_v = \frac{M_v}{L (\lambda_H + .00175)} \quad (5-4)$$

where  $M_v$  is the vertical monitor dimension. Similarly, the number of characters which can be displayed horizontally is:

$$N_w = \frac{M_w}{L (\lambda_w + .00175)} \quad (5-5)$$

where  $M_w$  is the horizontal monitor dimension. The total number of characters ( $N_t$ ) is the product of  $N_v$  and  $N_w$  or:

$$N_t = \frac{M_v M_w}{L^2 (\lambda_H + .00175) (\lambda_w + .00175)} \quad (5-6)$$

It is presently intended that a square format monitor will be used for the aft cabin CRT. The area remaining from display of a 3:4 aspect ratio imaged scene will be employed for numerical parameters associated with the scene. For a square format,  $M_v$  and  $M_w$  are equal and may be replaced by  $M$ . This yields:

$$N_t = \left[ \frac{M}{L} \right]^2 \left[ (\lambda_H + .00175) (\lambda_w + .00175) \right]^{-1} \quad (5-7)$$

The total number of characters which can be displayed thus depends on the square of the monitor dimension to viewing distance ratio and on the recognition visual angles.

The equations developed previously have all assumed that the line of sight of the operator is normal to the monitor face. In considering character displays, however, the observer might be attending primarily to some other display and referring to a character display from time to time. This situation might lead to oblique viewing. In such cases, a larger image size would be required to produce the necessary visual angle than would be required for viewing normal to the display. The effective image size in this case would be given approximately by:

$$I' = I \sin \theta \quad (5-8)$$

where  $I'$  = effective image size at angle  $\theta$   
 $I$  = image size  
 $\theta$  = angle between normal line of  
regard and oblique line of regard.

The required image sizes calculated from eqs. 5-2 and 5-3 must be set equal to  $I'$  and image size calculated via eq. 5-8 in the case of oblique viewing.

The equations presented here contain parameters relating to character recognition size. Since recognition size via television was considered likely to be greater than for direct vision but less than for arbitrary patterns, it was necessary to determine recognition size empirically.

For this reason, a character recognition test was performed in the MSFC Teleoperator Visual System Laboratory to determine character recognition size for video viewing. This test was performed using hard copy and a television camera. In the nominal case, a character generator would be employed for the CRT display. It is possible, however, that hard copy material might be placed in front of a television camera and the signal uplinked to the STS. While this mode would not be optimal, it might be used in off-nominal situations. In such cases, character contrast might vary and the signal-to-noise ratio of the uplink system would be relevant. Character generation via hard copy and video camera was employed for the current test because it represents a worst case. The data from such a test were considered applicable to the case where a character generator is used. In addition, the determination of recognition size requires control of displayed image size-including sizes which are below threshold. This is not feasible with currently available character generators because these systems present characters at a generous margin above the necessary recognition size.

The character styles actually used were chosen based on the standard type styles called out by Ref. 10. Since inclusion of a wide variety of character types in the test was beyond the scope of the present effort, it was considered appropriate to use the Futura type style required by Ref. 10 for crew systems. This coincides with the current planning to use Ref. 10 as the baseline crew systems standard for STS. Due to the fact of television presentation, however, it was considered desirable to depart from Ref. 10 in terms of height-to-stroke ratio. The requirements of Ref. 10 call for the use of Futura Demibold type (height-to-stroke ratio of 5:1 to 6:1) for dark characters on a light background (negative contrast). Futura Medium type (height-to-stroke ratio of 7:1 to 8:1) is called out for light characters on a dark background (positive contrast). In the present case, however, with a sufficiently great height-to-stroke ratio, recognition could be limited by stroke resolution. For example, for a height-to-stroke ratio of 8:1, resolution of the stroke based on the data of section 4.0 would require a stroke width producing a visual angle of 6 arc minutes. The corresponding letter height would be 48 arc minutes at a height-to-stroke ratio of 8:1. This would result in excessive character size and would reduce the number of characters which could be displayed not because this character size is necessary for recognition but because the character size is driven by the necessary stroke width for resolution. For this reason, it was considered advisable to reduce the height-to-stroke ratios by one "step" in the Futura type series in the two cases of positive and negative contrast. Accordingly, Futura Demibold (height-to-stroke ratio of 5.5:1)

was used for light figures on a dark background and Futura Bold (height-to-stroke ratio of 3.5:1) was used for dark figures on a light background.

These character formats were used to carry out an empirical test to determine recognition size for standard characters presented via television under variation in contrast, signal-to-noise ratio, and transmission mode. The test procedures and results are presented in section 6.0.

## 6.0 CHARACTER RECOGNITION TEST

The objective of the character recognition test was to determine the recognition size for alphanumeric characters presented via television under varying video system parameters.

### 6.1 Apparatus

The task apparatus for this experiment consisted of 12 alphanumeric matrices of 56 characters each. Three sizes of characters were utilized; 48 point (12 mm.), 24 point (5.5 mm. ) and 14 point (3.0 mm.), and two type styles corresponding to symbol/background contrasts were used; Futura Demi for light figures on a dark background, and Futura Bold for dark figures on a light background (Figure 6-1). The stroke-width-to-height ratio for Futura Demi was 1:5.5 and the stroke-width-to-height ratio for Futura Bold was 1:3.5. Three background mountings for the characters were utilized; white (.9), grey (.3), and black (.1). The light characters (.9) were affixed to the darker (.1, .3) backgrounds in a 7 x 8 matrix of alpha-numeric symbols which were drawn randomly from two complete alphabets (52) and from one set of numerals (1-9). Assignment of each number and letter at least once was assured by drawing all of the letters from alphabet "1" first, and all of the numbers from a separate source. Within a 56 character matrix each letter (A-Z) appears at least once and each number (1-9) appears only once.

The darker characters (.1) were affixed to the lighter background (.3) in the same manner as the other, lighter characters. It should be noted that both dark and light characters share a common background, that being .3. For one case, this yields a light figure on a dark background and for the other cases, yields a dark figure on a light background, and

FUTURA BOLD, 48 POINT, 12 mm.  
STROKE WIDTH-TO-HEIGHT 1:3.5

FUTURA DEMI, 48 POINT, 12 mm.  
STROKE WIDTH-TO-HEIGHT 1:5.5

FUTURA BOLD, 24 POINT, 5.5 mm.  
STROKE WIDTH-TO-HEIGHT 1:3.5

FUTURA DEMI, 24 POINT, 5.5 mm.  
STROKE WIDTH-TO-HEIGHT 1:5.5

FUTURA BOLD, 14 POINT, 3 mm.  
STROKE WIDTH-TO-HEIGHT 1:3.5

FUTURA DEMI, 14 POINT, 3 mm.  
STROKE WIDTH-TO-HEIGHT 1:5.5



FIGURE 6-1  
ALPHA-NUMERIC CHARACTER EXAMPLES

all combinations yield four contrast conditions: +90%, +67%, -20%, and -80%, when  $C = 100\% \frac{B-T}{B}$ . Each 56 character matrix of each size or each contrast was placed on a support panel and displayed behind a 8cm x 11 cm opening such that only one 3 x 4 character matrix was displayed at any one time. Each 12 character matrix constituted a recognition trial. Within each 7 x 8 character matrix, there are 25 individual and separate 3 x 4 character matrices.

The character matrices were displayed to each subject through a television system utilizing a single COHU Mod 2000 TV Camera and a 7.75 Conrac monitor. Signal transmission was through direct cabling. Transmission parameters could be manipulated by 1) introducing random Rf noise utilizing a GRC random noise generator, 2) by converting to a 4 bit digital signal utilizing a Computer Labs A/D and D/A converter, and 3) a narrow band pass filter could be introduced by the experimenter to band limit transmission to 1 MHz. The subject's and experimenter's stations are shown in Figure 6-2.

The display panel with its 8 cm x 11 cm aperture used for displaying any 12 character matrix was positioned on a task table in one of four predetermined positions, either 247 cm, 197 cm, 164 cm, and 145 cm, away from the camera lens. This allowed transmission of characters which varied in displayed size from 6.46 arc min. to 43.83 arc. min. (Table 1).

The character matrices were 7 x 8 cells, with each cell 25 mm square. This was the case regardless of the point size of the character. Each number or letter was positioned in the right lower corner of the cell.

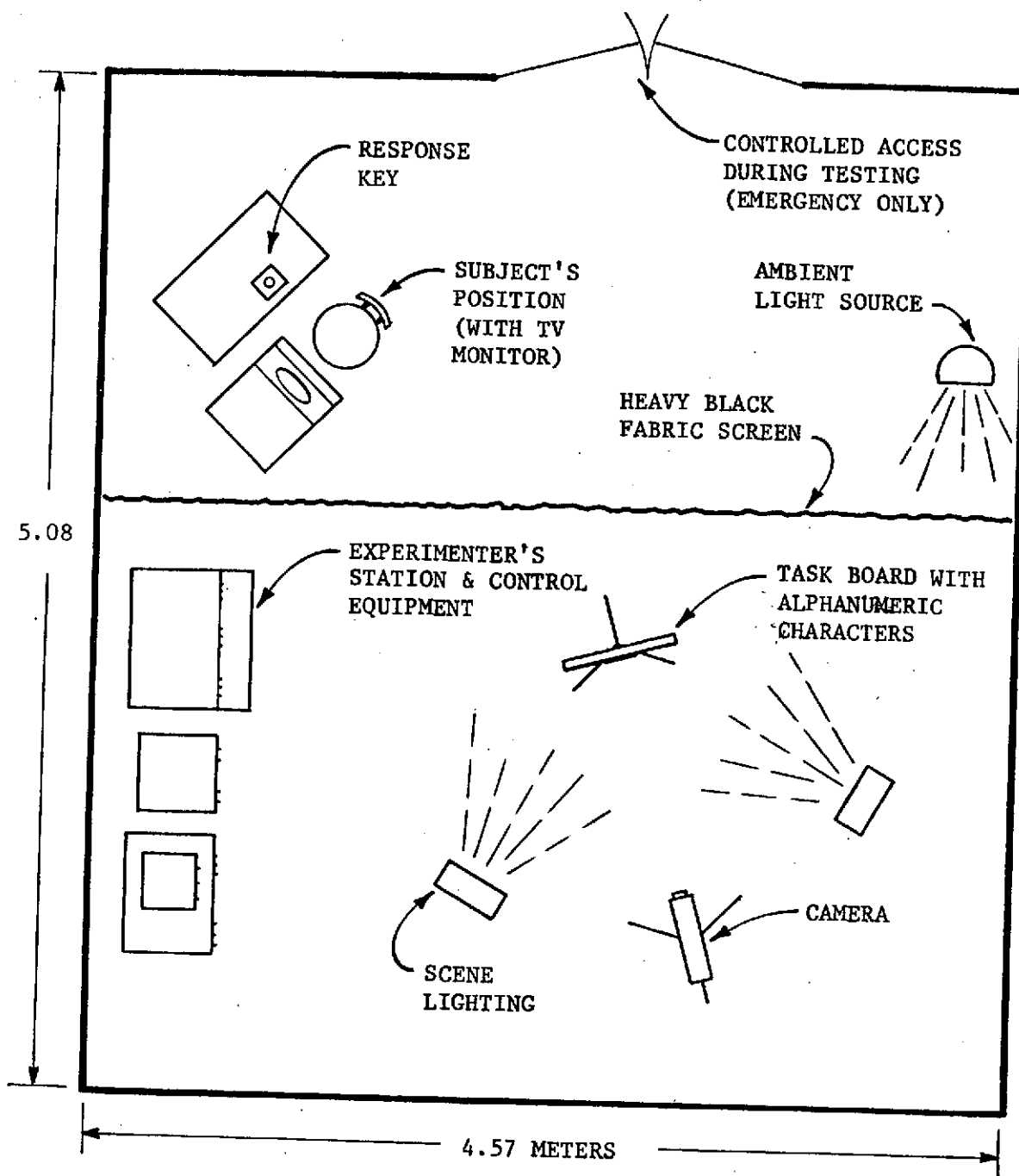


Figure 6-2. VISUAL SYSTEM LABORATORY ARRANGEMENT FOR CHARACTER RECOGNITION

CHARACTER SIZE	HT. MM. ACTUAL	HT MM IMAGE AT POS/	POSITION USED	MAGNIFICATION FACTOR	HT MM IMAGE AT POS. USED	VIS. ANGLE AT 21 IN. = 533.4 MM	
						RAD.	MIN.
SMALL } 1	3.0	1.000	1 Farthest from camera	1.00	1.00	.00188	6.46
SMALL }	3.0	1.000	3	1.50	1.50	.00281	9.66
MED } 2	5.5	1.833	2	1.25	2.29	.00429	14.75
MED }	5.5	1.833	4 Closest to camera	1.70	3.12	.00585	20.11
LARGE } 3	12.0	4.000	1	1.00	4.00	.00750	25.79
LARGE }	12.0	4.000	2	1.25	5.00	.00938	32.25
LARGE }	12.0	4.000	3	1.50	6.00	.01125	38.68
LARGE }	12.0	4.000	4	1.70	6.80	.01275	43.83

TABLE 6-1  
CHARACTER HEIGHTS

## 6.2 Experimental Design

The experimental subjects were drawn from a pool of NASA/MSFC volunteers. Five male subjects were used in this experiment, each screened for normal visual acuity and stereopsis using the standard Orthorator Eye Examination.

The independent variables manipulated in this experiment were:

1) Four levels (4) of Target/Background contrast.

- a) + 90% black on white
- b) + 67% black on gray
- c) - 20% white on gray
- d) - 80% white on black

2) Eight sizes (8) of displayed characters

- |            |            |
|------------|------------|
| a) 1.00 mm | e) 4.00 mm |
| b) 1.50 mm | f) 5.00 mm |
| c) 2.29 mm | g) 6.00 mm |
| d) 3.12 mm | h) 6.80 mm |

These character sizes are derived from the information in Table 6-1

3) Two (2) levels of signal to noise

- a) 32 db
- b) 15 db

4) Three (3) transmission parameters

- a) 4.5 MHz Analog
- b) 4.5 MHz BIT Digital
- c) 1.0 MHz Analog

Each character size was displayed to a subject under each condition for a total of 192 trials on a 3 x 4 character matrix for each subject. There were 300 possible 3 x 4 character matrices by contrast and initial size so all matrices were not displayed to each subject. Each matrix was, however, utilized at least three times among the five subjects.

Dependent variables were taken to include:

- 1) Time to respond to all 12 characters in a trial matrix.
- 2) The response accuracy in terms of correct identification of a single character or the type of error for a single character.

The control variables were held to the following levels:

- 1) Subject station ambient light; Level-one foot candle
- 2) Target peak white sensitivity; .8 Reflectance
- 3) Subject visual acuity; 20/20 corrected
- 4) Scene lighting conditions; 100 Foot candles
- 5) Time to respond per trial; 60 secs.

### 6.3 Procedure

Prior to testing, all laboratory equipment was activated and calibrated. Light levels, TV target sensitivity, and other control variables were set and allowed to stabilize prior to calibration.

The subjects were scheduled in the laboratory one at a time. They had a standard set of instructions read to them (Appendix D) and were situated at the display. Positioning was such that each subject viewed the monoptic display from 21 inches away and at an angle 15 degrees below the horizon. Ambient light in the subject's area was controlled to 1 foot candle. Controls were also established for unnecessary interruptions.

Once the subject was situated and understood the instructions, the experimenter proceeded to set up the first test trial. From a predesigned data sheet, the experimenter selected the appropriate task panel position from the four (4) available. He selected the one character size from three (3) utilized and the appropriate contrast condition to be tested. The experimenter then aligned the predetermined 3 x 4 matrix with the viewing aperture, selected the signal of this 3 x 4 matrix to the subject. The subject responded by identifying each of the 12 characters in the 3 x 4 matrix, reading from left to right, top to bottom. The experimenter recorded any errors in character recognition by specifying the correct

character with the corresponding error. Total response time to recognize all 12 characters was recorded. Following one trial on a 3 x 4 matrix, the experimenter selected the next predetermined arrangement of independent variables and proceeded to the next trial. Each subject received 192 trials.

The eight image size conditions are summarized in Table 6-1. The variation in image size was produced by combinations of target size and target-to-camera distance. The camera/target geometry for the test is depicted in Figure 6-3. The character sets employed are depicted in Figure 6-1.

#### 6.4 Results

The raw data obtained from the character recognition test consisted of the number of errors made on each trial which varied from zero to twelve. These data were subjected to a five way analysis of variance assuming all factors except subjects to be fixed. The source table resulting from the analysis of variance is shown as Table 6-2.

Table 6-2 shows all four independent variables to influence the recognition error rate. As would be expected, error rate decreased with increases in image size, signal-to-noise ratio, and bandwidth. The contrast effect, however, suggests that contrast reduction degrades performance to a greater extent for characters having positive contrast (light on dark) than for those having negative contrast (dark on light). This effect is shown in Figure 6-4 which illustrates the joint effects of contrast and transmission mode. The significant main effect of transmission mode appears to be due to the degradation in performance introduced by bandwidth limiting. The data suggest that use of the digital

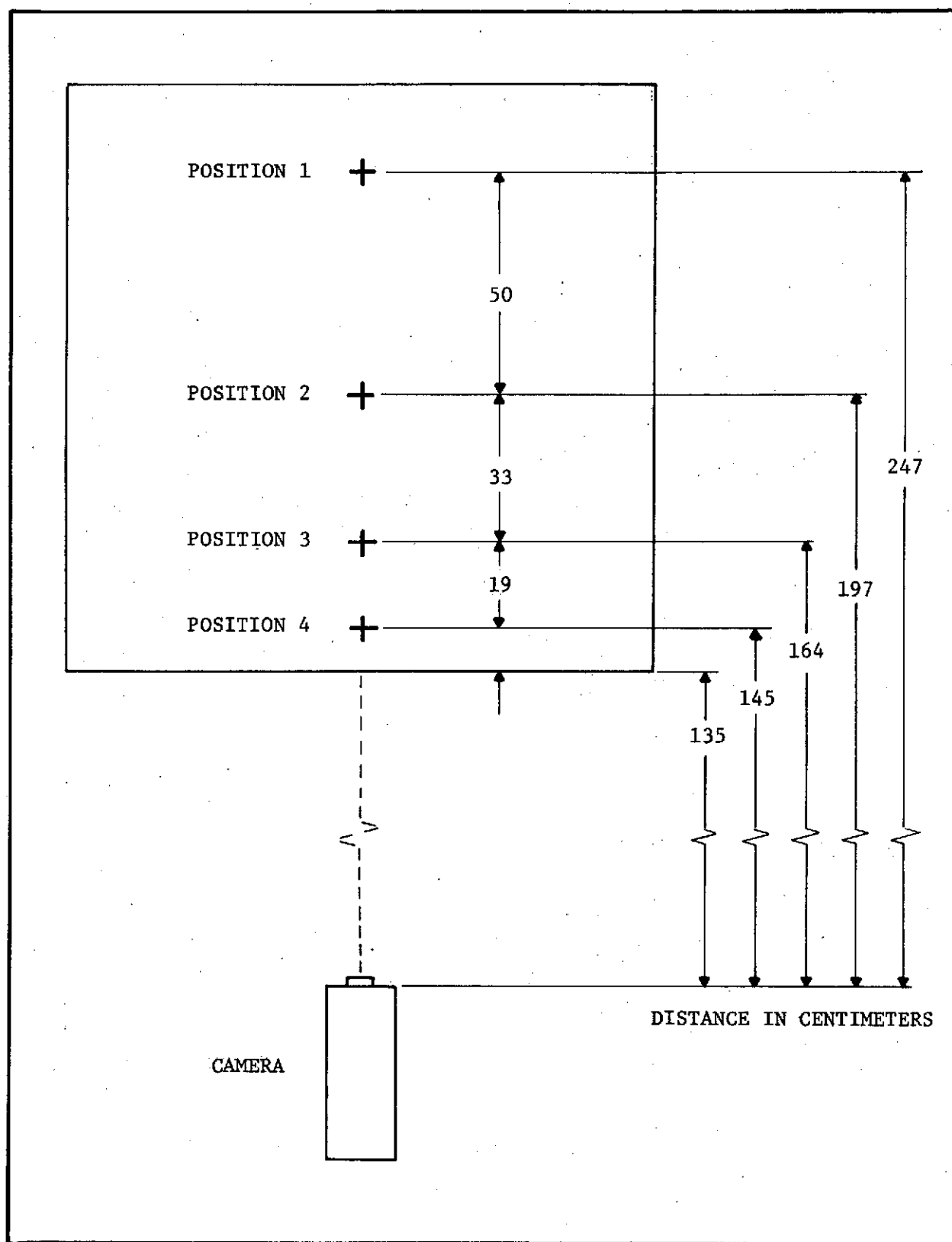


FIGURE 6-3. TARGET POSITIONS USED TO DERIVE APPROPRIATE IMAGE SIZES

TABLE 6-2

ANALYSIS OF VARIANCE OF FREQUENCY OF CHARACTER RECOGNITION ERRORS

<u>Source</u>	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Contrast (C)	3	440.75	146.91	46.14 **
Image Size (K)	7	12385.04	1769.26	206.96 **
Trans Mode (T)	2	1594.88	197.44	200.96 **
S/N Ratio (N)	1	1346.63	1346.63	57.41 **
Subjects (S)	4	99.42	24.86	
CK	21	273.03	13.00	3.26 **
CT	6	77.47	12.91	3.06 *
KT	14	659.10	47.08	6.48 **
CN	3	419.60	139.86	33.01 **
KN	7	745.82	106.55	29.91 **
TN	2	292.69	146.34	77.60 **
CS	12	38.21	3.81	
KS	28	239.38	8.55	
TS	8	31.75	3.97	
NS	4	93.82	23.45	
CKT	42	419.61	9.99	2.11 **
CKN	21	326.69	15.56	3.80 **
CTN	6	48.54	8.09	1.91
KTN	14	823.94	58.85	18.30 **
CKS	84	335.44	3.99	
CTS	24	101.27	4.22	
KTS	56	406.69	7.26	
CNS	12	50.85	4.24	
KNS	28	99.74	3.56	
TNS	8	15.09	1.89	
CKTN	42	397.53	9.47	2.30 **
CKTS	168	796.78	4.74	
CKNS	84	343.63	4.09	
CTNS	24	101.84	4.24	
KTNS	56	180.09	3.22	
CKTNS	168	691.88	4.12	

\* Significant at .05 Level

\*\* Significant at .01 Level

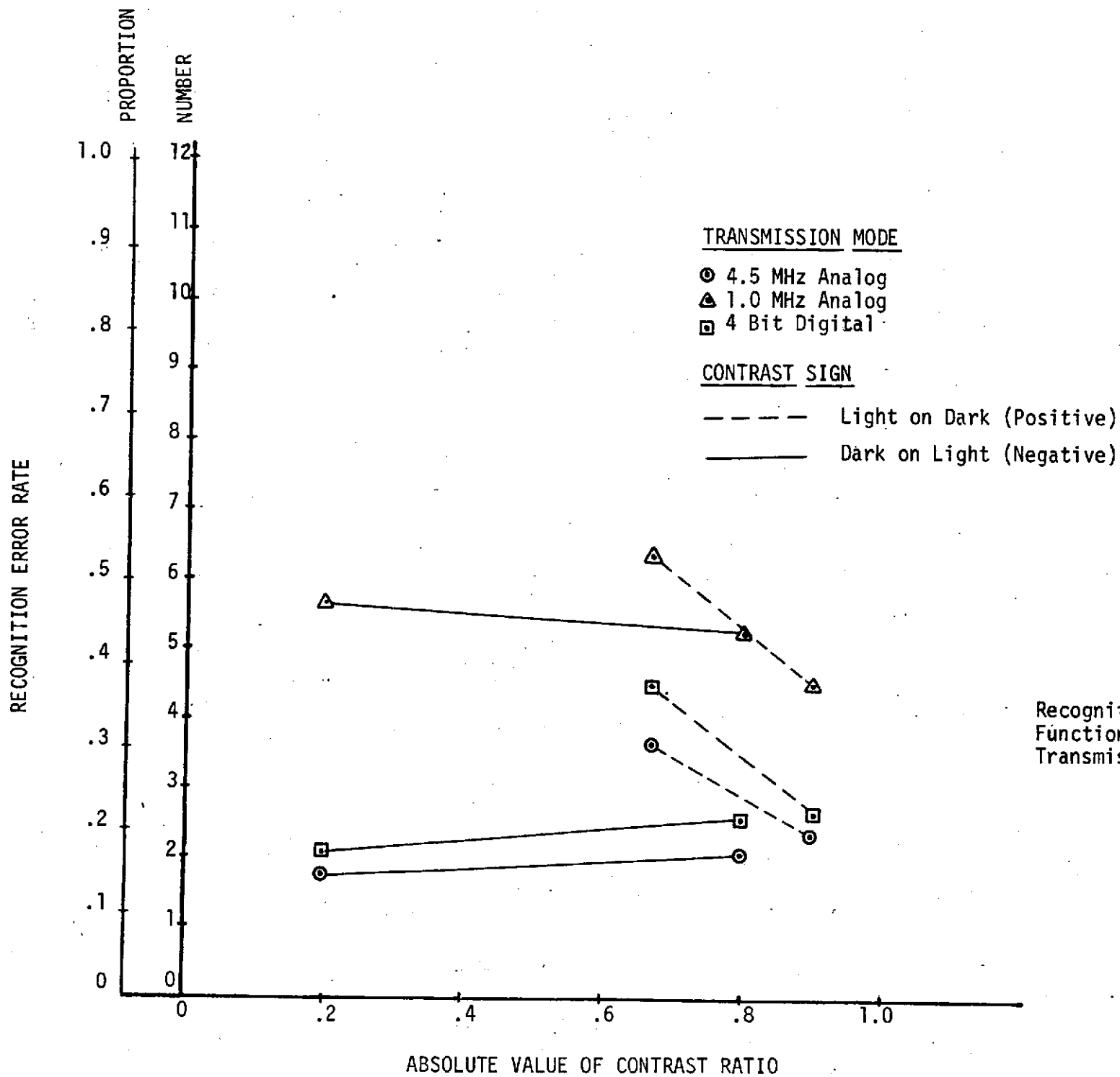


FIGURE 6-4

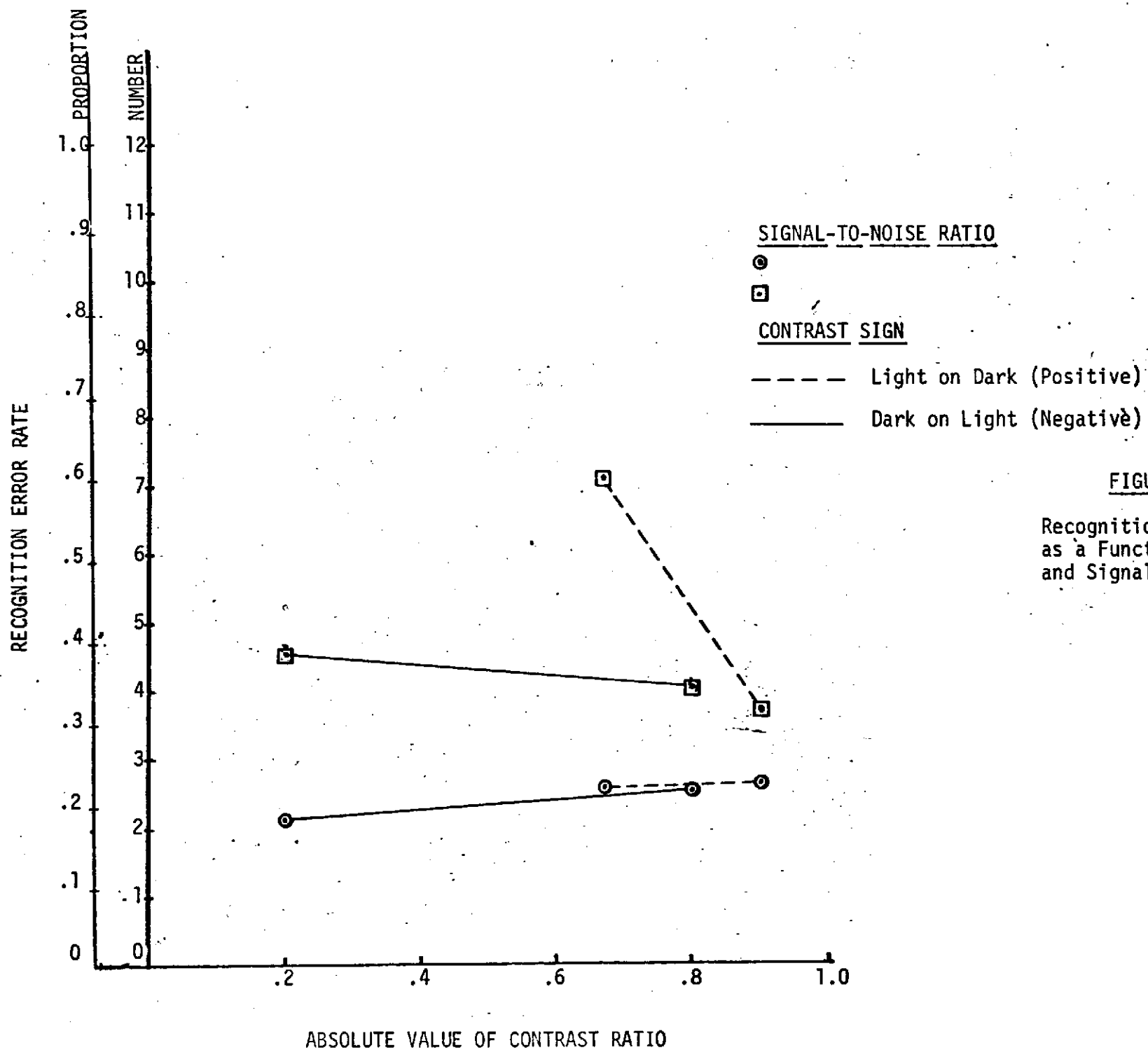
Recognition Error Rate As A  
Function of Contrast and  
Transmission Mode

transmission mode results in little impairment of performance relative to a 4.5 MHz bandwidth. The interaction effect is largely due to the difference noted for positive and negative contrast values. In the case of negative contrast, little effect of reduction in absolute contrast ratio is evident down to the value of  $-.20$ . For the positive contrast, however, a strong contrast effect is evident, reduction in contrast from  $+0.9$  to  $+0.67$  producing a marked increase in the recognition error rate at all levels of transmission mode. The contrast main effect is primarily due to the degradation of performance associated with the  $+0.67$  contrast level relative to the other three contrast levels investigated.

The interaction of contrast and signal-to-noise ratio was found to be significant at the  $.01$  level. The joint effects of these variables are shown in Figure 6-5. The data show the general increase in error rate with signal-to-noise ratio reduction from 32 to 15 db. The effect of contrast in Figure 6-5 depends on which level of signal-to-noise ratio is considered. Within the levels of absolute contrast employed, contrast may be seen not to influence error rate for the 32 db S/N ratio. Contrast, however, does influence error rate with the 15 db S/N ratio. Under this condition, the positive contrast effect may be seen to be more pronounced than the negative contrast effect. Thus, the extent to which reduction in character contrast influences performance depends on both transmission mode and S/N ratio.

The independent variable of primary interest in the present context is visual angle subtended by the character. Table 6-2 shows image size to exhibit a main effect significant at the  $.01$  level and a variety of interactive effects. The joint effects of contrast and visual angle subtended by character height are shown in Figure 6-6. The functional form

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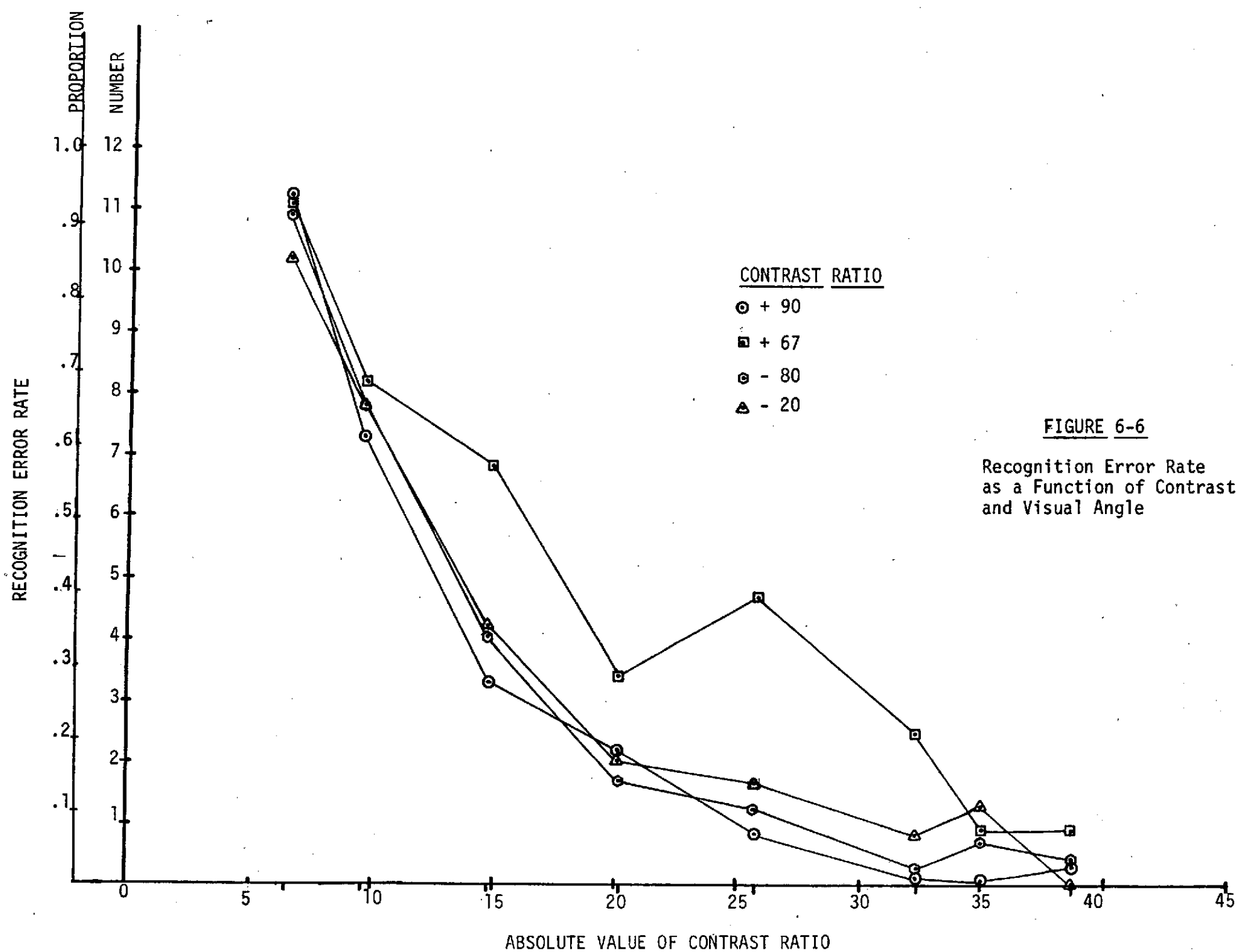


FIGURE 6-6

Recognition Error Rate  
as a Function of Contrast  
and Visual Angle

of the data of Figure 6-6 appears to be generally exponential. This corresponds to the general result obtained from previous studies of direct vision character recognition. The curves appear to be highly similar except for the +.67 contrast ratio curve which departs from the other contrast level curves. The data of Figure 6-6 appear to reach asymptotically low error rates at approximately 40 arc minutes of visual angle which is in apparent agreement with the recognition data of section 4.0. However, character height exceeds character width so that the crucial dimension for recognition would be width. Since width varies from letter to letter, no deterministic value for letter width can be given. The average character width can be employed, however. For the character sets used, the average width is about 77% of letter height. This yields about 31 arc minutes for asymptotic recognition error rate which is consistent with the reported tendency for letters to be recognizable at smaller visual angles than arbitrary patterns (Ref. 9).

The interaction of image size, signal-to-noise ratio, and transmission mode is shown in Figure 6-7. This figure presents the data of primary interest in the current context. In Figure 6-7, error functions for visual angle are shown for each combination of signal-to-noise ratio and transmission mode. The interaction of these two variables is due to the extreme departure of the 15 db 1 MHz system from the other systems. A similar result is shown for the task of resolution in Appendix A.

Figure 6-7 permits establishment of visual angle requirements for a particular set of system parameters. The data are averaged over contrast ratio so that they are valid even if there is some variation in contrast in materials displayed during STS operations. In accord with the system

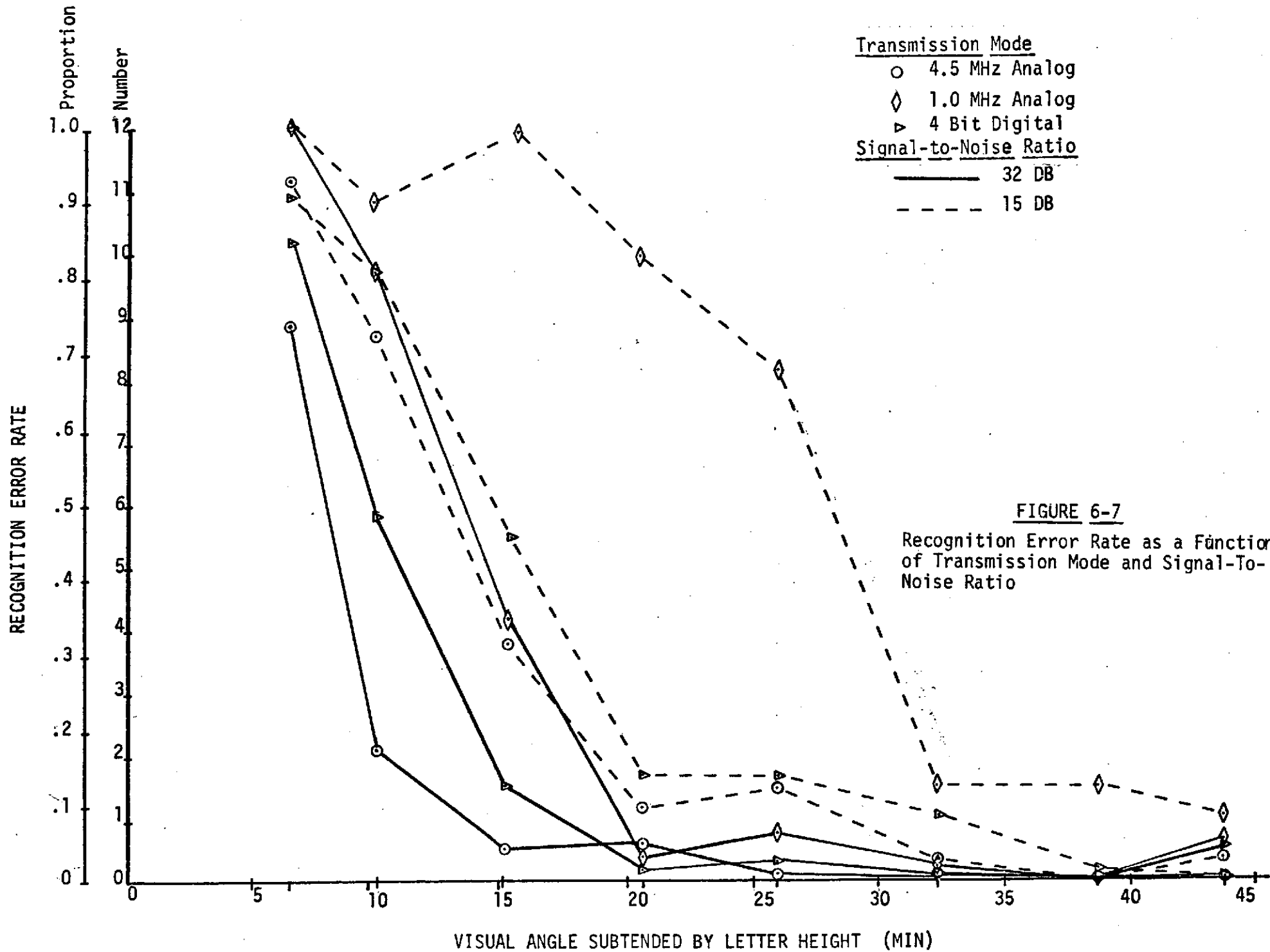


FIGURE 6-7

Recognition Error Rate as a Function of Transmission Mode and Signal-To-Noise Ratio

parameter assumptions made in previous sections, the curve for the 32 db/4.5 MHz system is of relevance for the determination of required character size. For this condition, performance is not strongly influenced by contrast reduction within the range studied here. The appropriate curve of Figure 6-7 exceeds the .99 recognition probability level in the vicinity of 30 arc minutes. Since this angle is that for letter height, the corresponding average letter width subtends about 23 arc minutes. For the maximum height to stroke ratio employed which was 5.5 to 1 in the case of the Futura Demibold type, the corresponding visual angle subtended by the stroke would be about 5.5 arc minutes which is in close agreement with the value of 6.0 arc minutes which was taken as the resolution visual angle in section 4.0.

The present data are thus consistent with the data of Appendixes A and B and with the general results of studies of character recognition using direct vision. The required visual angles for character recognition using the standard characters employed here may be taken to be 30 arc minutes (.0087 rad.) in height and 23 arc minutes (.0067 radians) in average width. These requirements are based on a signal-to-noise ratio of 32 db and bandwidth of 4.5 MHz.

## 7.0 CONCLUSIONS AND RECOMMENDATIONS

This section utilizes results developed in previous sections to determine a recommended monitor size for the orbiter aft cabin CRT displays. The equations and viewing constraints developed in previous sections were used in conjunction with field-of-view and resolution requirements associated with STS payloads to ascertain the required monitor size. Since precise requirements in terms of pattern recognition, range rate detection, and number of characters to be displayed were not available, these capabilities were projected based on the recommended monitor size. These findings are presented in the remainder of section 7.0.

### 7.1 Imaged Scene Viewing Requirements

Section 4.0 presents the relationships between video parameters necessary to provide adequate performance of visual tasks based on analytical and empirical data. The present section presents viewing requirements derived from selected STS mission operations and the resulting monitor size requirements.

The requirements derived include field of view and resolution/detection requirements as available from STS documentation and related studies. The requirements located are based on Refs. (3,5, and 7) and are summarized in Table 7-1. Most of the tabled field of view and detection requirements were taken from Ref. 3 which dealt with a wide variety of payload related operations. The teleoperator data were taken from Ref. 5 which was based on teleoperator video requirements resulting from acquisition, docking, and servicing of satellites. The data gathered from the SSPD sheets (Ref. 7) were sparse as regards resolution/detection requirements. While field-of-view requirements are given for most payloads to which this parameter applies, only one resolution/detection requirement was located-18 arc

TABLE 7-1

	<u>SOURCE</u>	<u>FIELD OF VIEW (DEG)</u>	<u>DETECTION/ RESOLUTION R/T</u>	<u>REQUIRED RATIO OF MONITOR WIDTH TO VIEWING DISTANCE (7° FOV)</u>
CAPTURE AND RETRIEVE FREE-FLYING PAYLOAD (LST)	3	30	63.7	.011
DEPLOY SEARCH & RESCUE/IMAGING RADAR ANTENNA (ATL)	3	45	120.0	.021
DEPLOY ANTENNA & LOAD FILM (ATL)	3	10	229.2	.039
DEPLOY ANTENNA, LOAD FILM, & DEPLOY BOOMS (ATL)	3	10	229.2	.039
OPEN PAYLOAD DOOR (SIRIF)	3	45	229.2	.039
DEPLOY CONTAMINATION SHROUD (LST)	3	45	31.3	.005
RETRACT SOLAR PANEL (LST)	3	45	114.6	.020
LOAD FILM (ASF)	3	60	229.2	.039
RETRACT ANTENNA & CHANGE FEEDS (COM-NAV)	3	10	687.6	.118
DEPLOY CONTAMINATION MONITORS (ATL)	3	20	28.7	.005
CONNECT/DISCONNECT PAYLOAD UMBILICAL (TUG)	3	45	245.6	.042
REMOVE/REPLACE MODULES (LST)	3	7	687.6	.118
DEPLOY RENDEZVOUS SENSOR	3	65	59.3	.010
REPAIR PAYLOAD RETENTION LOCK	3	27	122.8	.021
REPAIR PAYLOAD BAY DOOR	3	45	114.6	.020
REPAIR STAR TRACKER DOOR	3	15	114.6	.020
SUPPORT EVA RESCUE	3	15	57.3	.010
REMOVE TELESCOPE WINDOW (SIRTF)	3	45	57.3	.010
SATELLITE (BES) ACQUISITION BY FFTO	3	45	2000.0	.342
SERVICING BY FFTO	5	4	1538.0	.263
HE-11-S FIELD MONITOR OBSERVATION	5	40	11454.8	1.959
	7	35		

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sec. for the field monitor used for the High Energy Astrophysics payload HE-11-S. This degree of resolution is beyond the scope of the video system being considered here for general bay viewing. The HE-11-S documentation specifically calls out a 1024 x 1024 picture element capability. This would require a 1024 line video system with approximately three times the horizontal resolution being considered here. Since the present analysis is concerned with monitor size, the HE-11-S requirement was not considered further since the limitation here would be in terms of system resolution-not monitor size.

To obtain monitor size constraints based on the data of Table 7-1, the assumption was made that the video system would provide a zoom capability approximately equal to that of presently available space qualified cameras. To estimate this zoom range, the NASA/Lockheed camera was taken as typical. This camera provides a zoom range of approximately 8 to 1 extending from a 7 degree field of view to 55 degrees (diagonal). Assuming that the field of view figures of Table 7-1 refer to the horizontal field, this zoom range would satisfy all the operations of Table 7-1 except solar panel retraction (60 degrees FOV), module removal and replacement (65 degrees) and satellite acquisition by the FFTO (4 degrees). The latter requirement, however, is not strict. It was selected to provide adequate resolution for satellite acquisition.

Assuming that the detection/resolution requirements of Table 7-1 may be met by adjusting the zoom optics to the minimum field of view, the required monitor-width-to-viewing-distance ratios may be calculated via eq. 4-7. In all cases, the field of view assumed for this calculation is the minimum field of view of 7 degrees diagonal (5.6 degrees horizontal). The resulting monitor-width-to-viewing-distance ratios are shown in Table 7-1.

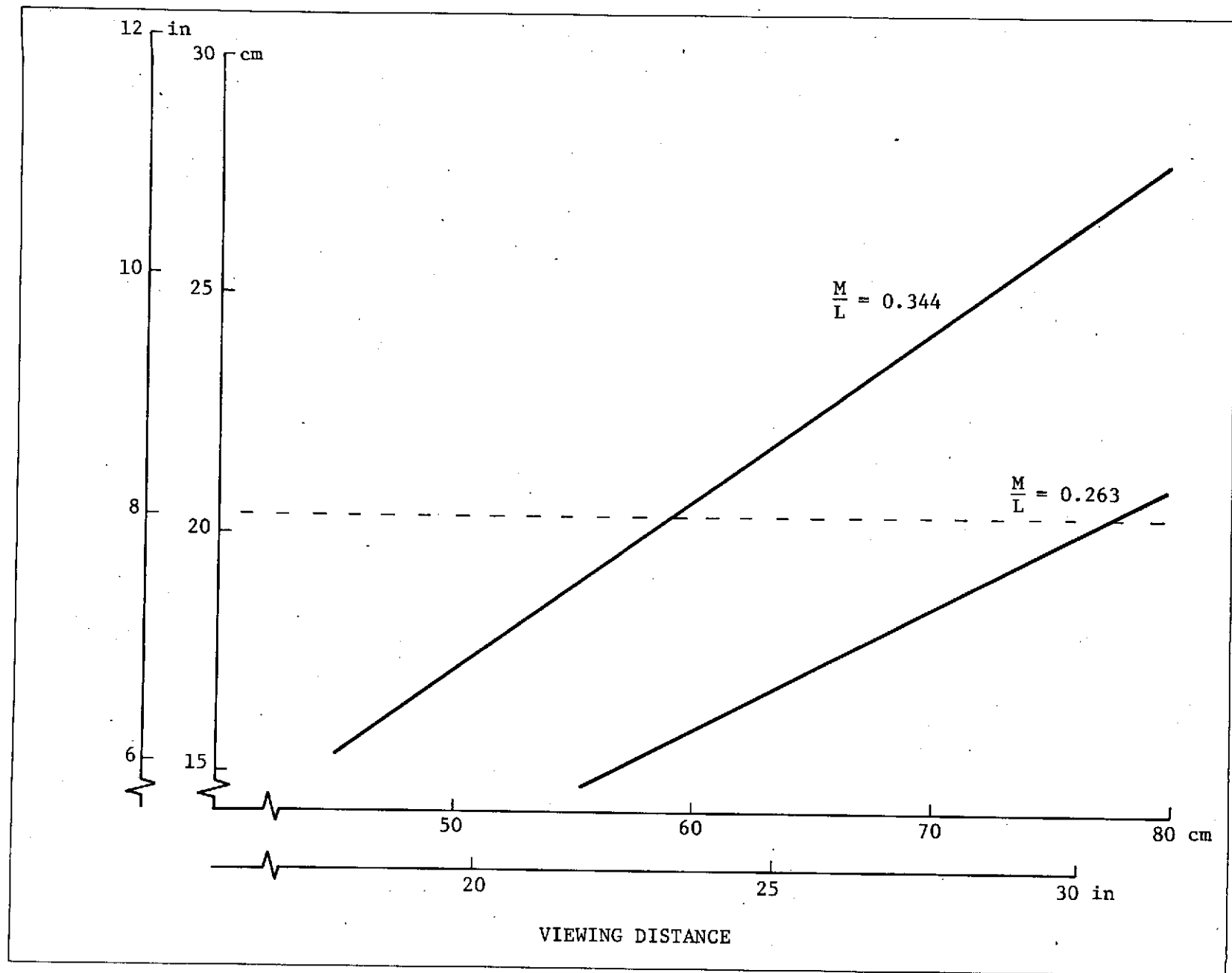


FIGURE 7-1. MONITOR WIDTH AS A FUNCTION OF VIEWING DISTANCE

The ratio of 1.959 for the HE-11-S viewing requirement is theoretical. This monitor-to-viewing distance ratio would not yield detection since system resolution would constrain performance. A suitable video system would require much greater resolution than that being assumed here and the monitor for this system would presumably be payload provided.

The maximum monitor width-to-viewing-distance ratio found elsewhere in the table is .342 required for satellite acquisition. This requirement would be relaxed if the desired 4 degree field of view were available. In this case, the servicing operation would then drive the monitor-width-to-viewing-distance ratio. In general, the requirements associated with the free-flying teleoperator are much more stringent than are those for the typical payload operations.

Examination of the monitor-width-to-viewing-distance ratios for the typical payload operations shows a worst case of .118 which could be satisfied with fairly modest monitor dimensions. The worst case ratio in Table 7-1 is then .263 or .342 depending on the availability of a 4 degree field of view video system. Figure 7-1 shows required monitor dimensions for these two values of monitor-width-to-viewing-distance ratios over the general range of viewing distances encountered for typical control station layouts.

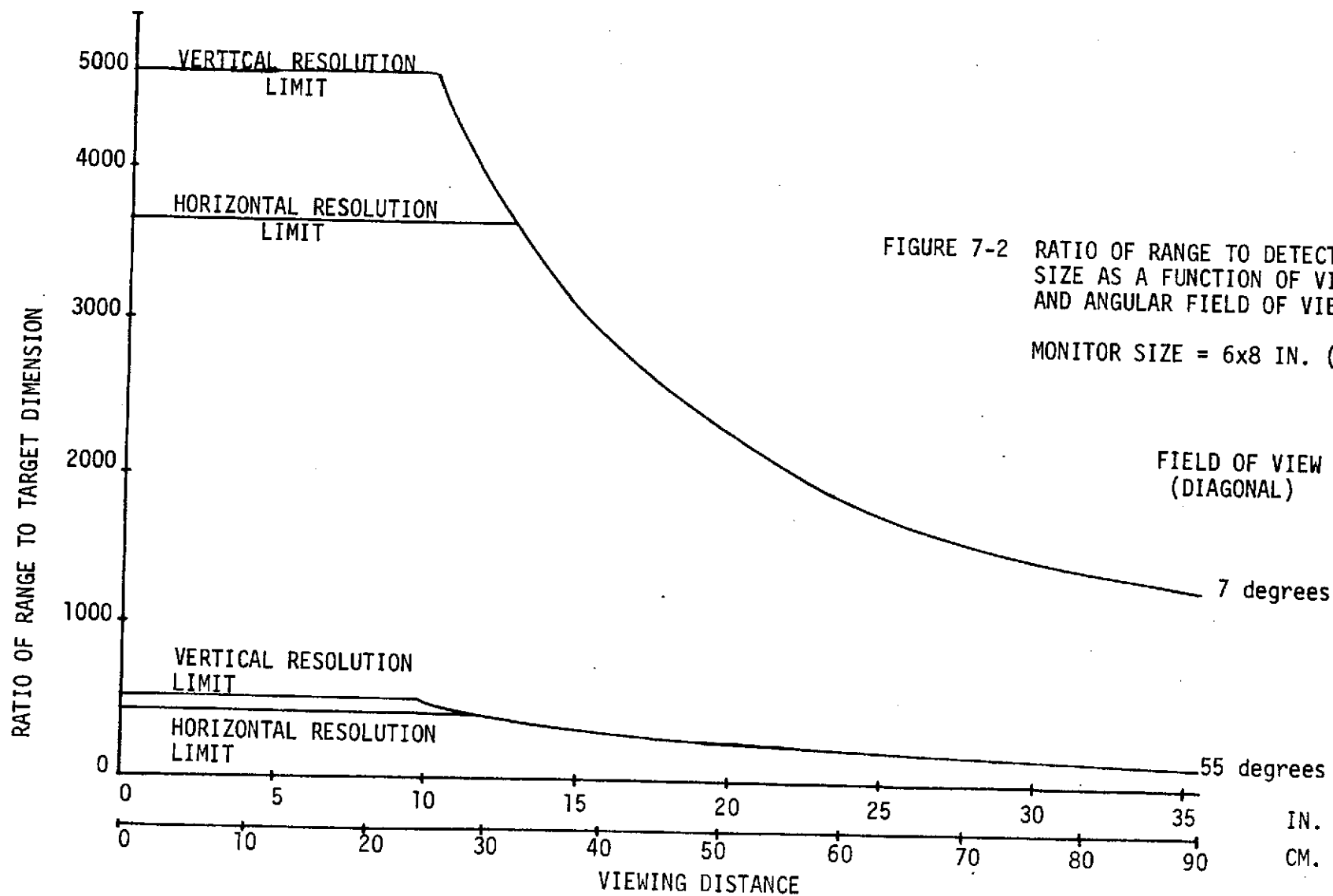
The choice of a monitor size based on the available data depends on the discrete values of screen size of available monitors. A commonly available size is a screen area of 20.3 by 15.2 cm ( 8 x 6 in.). This monitor would satisfy the FFTO servicing requirement out to a viewing distance of 78.5 cm (31 in.) and would more than satisfy the typical

payload operation requirements of Table 5-1.

Assuming a 20 cm x 15 cm monitor size for the imaged scene portion of the CRT display, it follows that a square monitor having 20 by 20 cm. (8 x 8 in.) useable viewing area would provide a 3:4 aspect ratio (15 x 20 cm.) (6 x 8 in) imaged scene display area with an additional 5 by 20 cm (2 x 8 in) space for alphanumeric character display. If this monitor size is assumed, together with the previously stated video system parameters, the parametric curves for detection/resolution, recognition, and range rate detection can be generated.

#### Resolution/Detection

The limits of detection performance assuming a 15 by 20 cm (6 by 8 in) viewing area may be determined by means of eq. 4-9. Figure 7-2 shows the ratio of range to minimum detectable target size as a function of viewing distance. The curves are shown for 7 and 55 degree (diagonal) fields of view and a 15 by 20 cm. (6 by 8 in.) viewing area. Comparing Figure 7-2 with the resolution requirements data of Table 7-1, it can be seen that the proposed monitor size will permit detection of the BES satellite at a viewing distance of about 58 cm (23 in.). This viewing distance is somewhat below the 71 cm. (28 in) considered standard by Ref. 9. The required viewing distance could be achieved, however, by suitable attention to this requirement during the FFTO panel design. The recommended monitor dimension can easily accommodate the viewing requirements of Table 7-1 based on general viewing of the Orbiter bay. In this connection, it is interesting to note that the minimum target size encountered in Ref. 3 was .6 cm (.25 in.) which is the width of a film associated with ATL payloads. If this film were



located at the extreme end of the Orbiter bay with a range of approximately 18.28 m. (60 ft), the range-to-target size ratio would be 2880. Figure 7-2 shows that this target could be resolved by the recommended system. Since this represents the maximum viewing requirement possible based on current data, there is little reason to suppose that a monitor larger than the one recommended would be required.

### Recognition

Viewing requirements based on pattern recognition were not located by the present study. Presumably, the operations and visual tasks required by STS missions are not adequately defined at present. The recognition limits can be developed for the recommended video system based on the data of section 4.0. These limits can then be examined and a judgment made as to adequacy. The recognition constraints discussed in section 4.0 using the parameters of the proposed system are shown in Figure 7-3 subject to constraints imposed by system resolution. For a 7 degree field of view (diagonal) which would be obtained at the maximum zoom setting of the optics system assumed, a range-to-target-width ratio of about 306 is obtained at the minimum useable viewing distance of 58 cm (23 in.). This would permit recognition of an object 6 cm (2.4 in) wide at the end of the Orbiter bay. The vertical resolution limit would permit recognition of an object about 4.8 cm (1.9 in) high at the end of the bay. At a viewing distance of 71 cm (28 in), an object 7.3 cm (2.9 in) across should be recognizable at the end of the orbiter bay. While no pattern recognition requirements are presently known, the proposed system should permit recognition of objects having

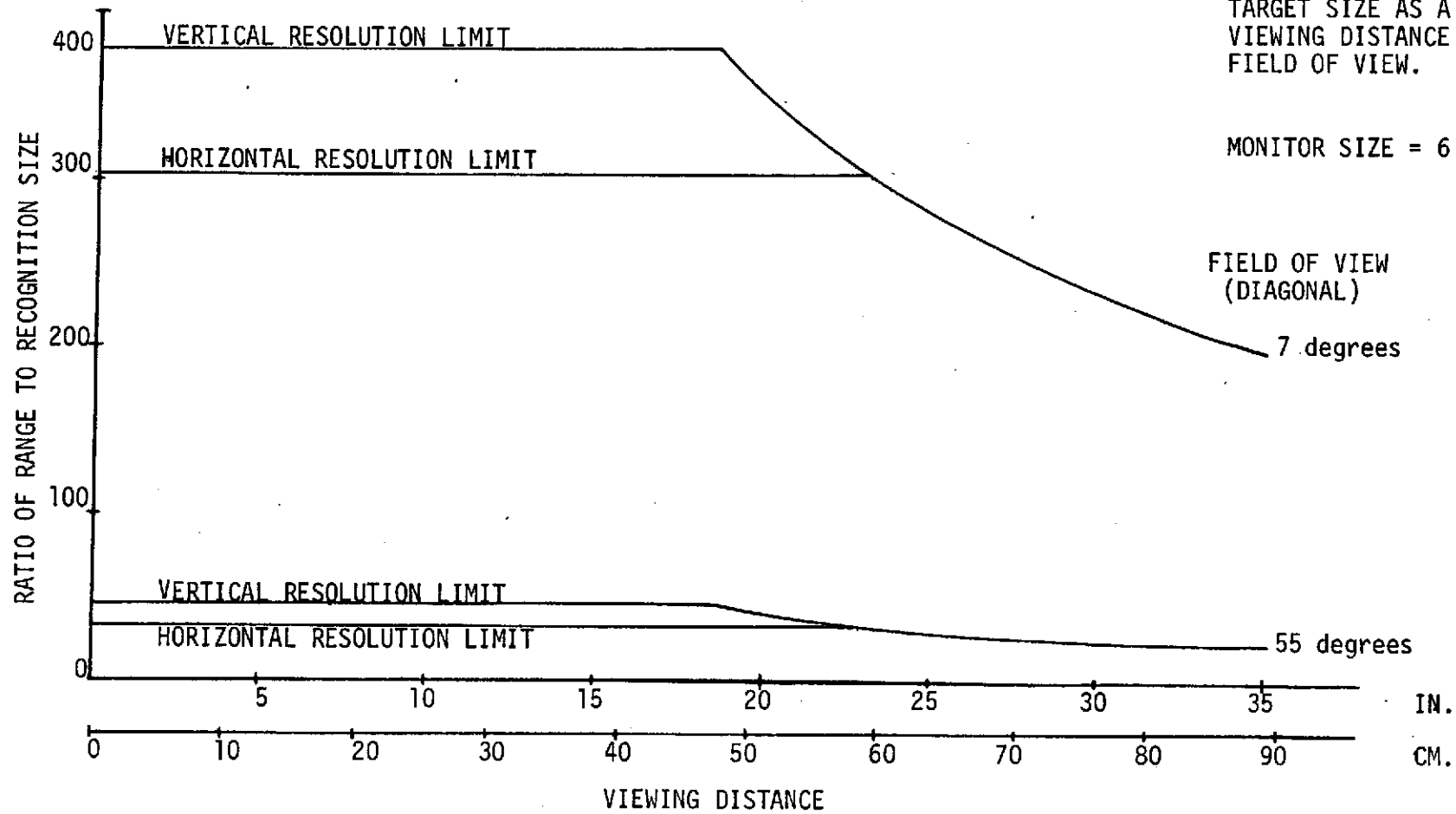


FIGURE 7-3 RATIO OF RANGE TO RECOGNITION TARGET SIZE AS A FUNCTION OF VIEWING DISTANCE AND ANGULAR FIELD OF VIEW.

MONITOR SIZE = 6 x 8 IN. (15x20)

FIELD OF VIEW  
(DIAGONAL)  
7 degrees

55 degrees

dimensions of a few inches at the length of the orbiter bay should prove adequate.

The data for a 71 cm (28 in) viewing distance are shown in Figure 7-4 which shows the minimum target dimensions for detection and resolution as a function of range. The curves are shown for 7 and 55 degrees (diagonal) fields of view.

#### Range Rate Detection

Figure 7-5 shows the minimum detectable range rate as a function of range for the proposed system. Curves are presented for three different viewing distances. While range rate or motion detection requirements for STS orbital operations are not generally known, Ref. 1 discusses the approach of the FFTO to the BES satellite. This approach calls for nulling range rate at a range of 6.1 m (20 ft.). Figure 7-5 shows a range rate threshold of about .01 to .02 m. per sec. (.03 to .06 ft/sec) at this range. Residual rates of this magnitude would appear acceptable.

In general, the proposed monitor size of 15.2 by 20.3 cm (6 by 8 in) appears to satisfy the resolution requirements presented. In cases of recognition and range rate detection where specific requirements are not readily available, this monitor size appears to provide considerable capability relative to expected requirements.

#### 7.2 Character Display Viewing Requirements

The visual angles for character recognition were determined by the test reported in section 6.0. These data may be summarized as follows:

- . Average character width visual angle for  
.99 recognition probability .00669 rad.
- . Corresponding character height visual angle .00873 rad.
- . Spacing between characters .00175 rad.

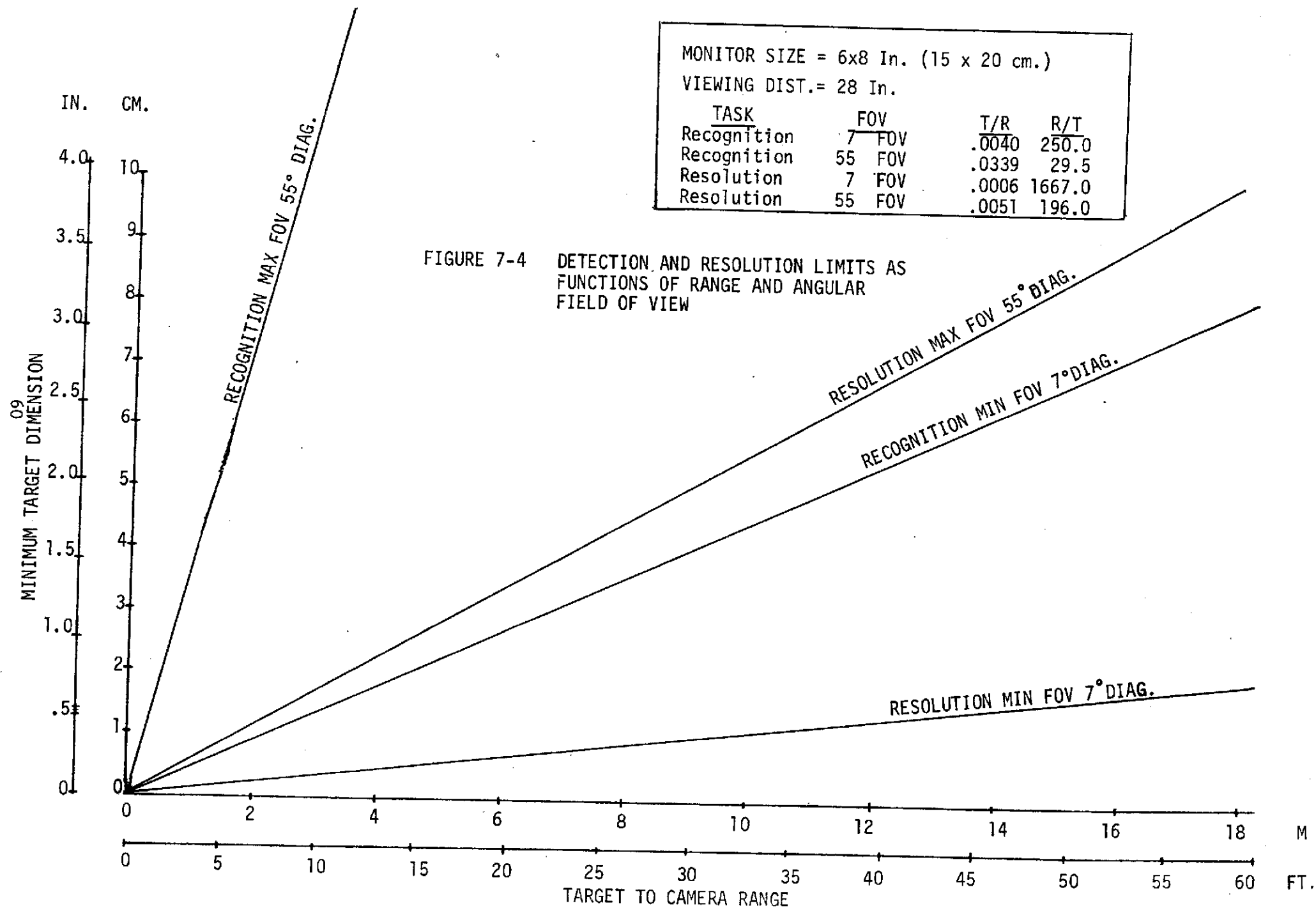
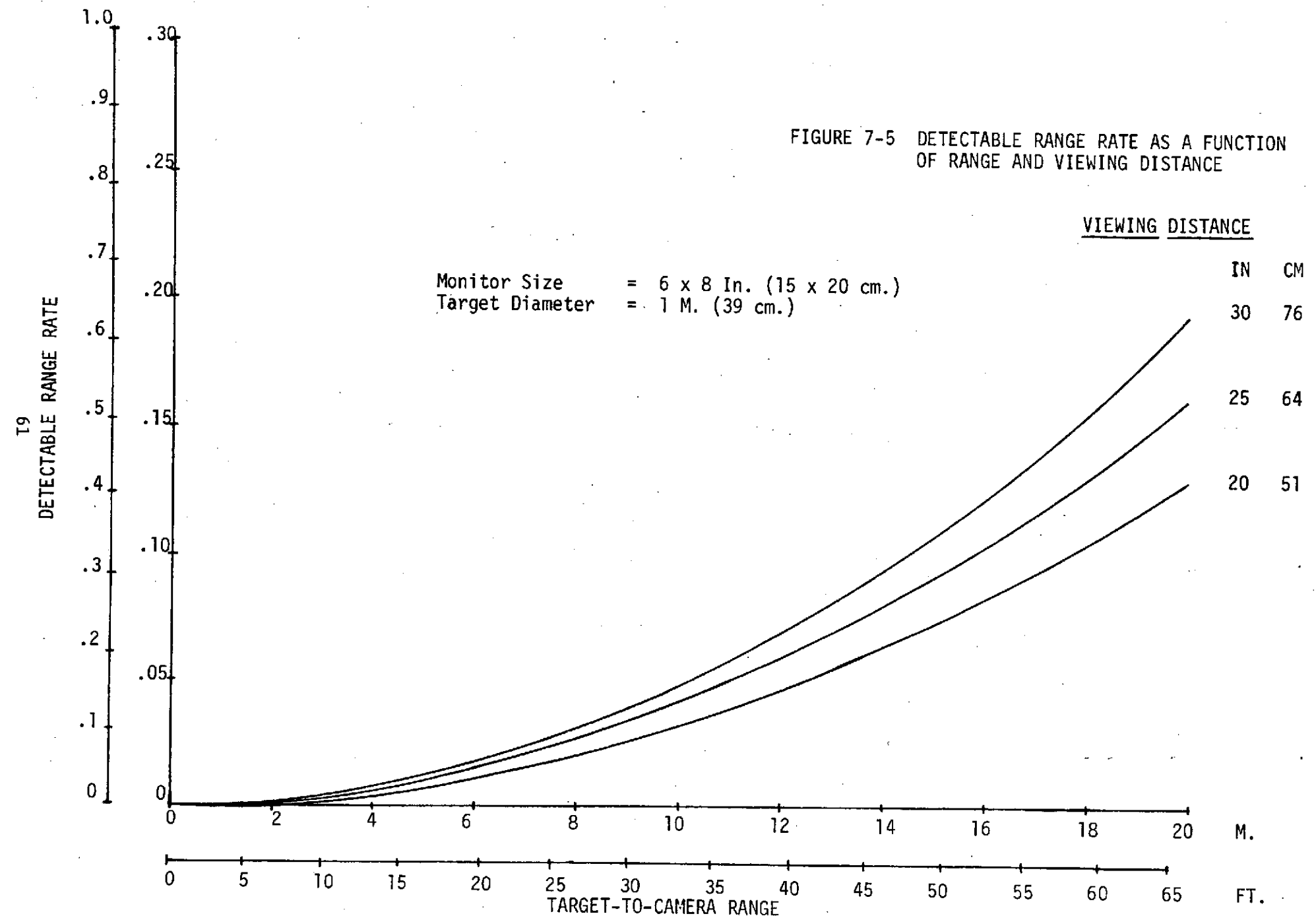


FIGURE 7-5 DETECTABLE RANGE RATE AS A FUNCTION OF RANGE AND VIEWING DISTANCE



These parameter values may be substituted in eq. 5-7 to provide the total number of characters per display area.

$$N_t = \left[ \frac{M}{L} \right]^2 11363.636 \quad (7-1)$$

Equation 7-1 is subject to the constraint of system resolution. Table 4-2 gives the maximum useable monitor dimension to viewing distance ratio as .436. This is based on the diagonal monitor dimension. For a square monitor format, the corresponding width (or height) to viewing distance ratio is .308. Substituting this figure in eq. 7-1 yields about 1080 as the maximum number of characters which can be displayed at once based on a 4.5 MHz bandwidth system. Eq. 7-1 is plotted parametrically in Figure 7-6.

The 20 by 20 cm (8 x 8 in) monitor size considered in a previous section would permit a maximum of about 930 characters to be recognized at a viewing distance of 71 cm (28 in). The maximum number of characters based on the horizontal resolution requirement would be about 1080. This corresponds to about 72 percent of the number of characters on a double spaced type written sheet. This maximum number of characters would be realized at a viewing distance of about 66 cm (26 in) with a 20 by 20 cm (8 by 8 in) monitor. If 71 cm (28 in) is taken as the standard viewing distance, 930 characters or 86 percent of maximum could be resolved. The number of recognizable characters drops to about 600 at a viewing distance of 89 cm (35 in).

The data presented thus far for number of recognizable characters assumes one discriminable line width between characters vertically, as well as horizontally. This is close spacing for lines of type. Ref. 10 calls out one half of a character height as the spacing between lines for printed

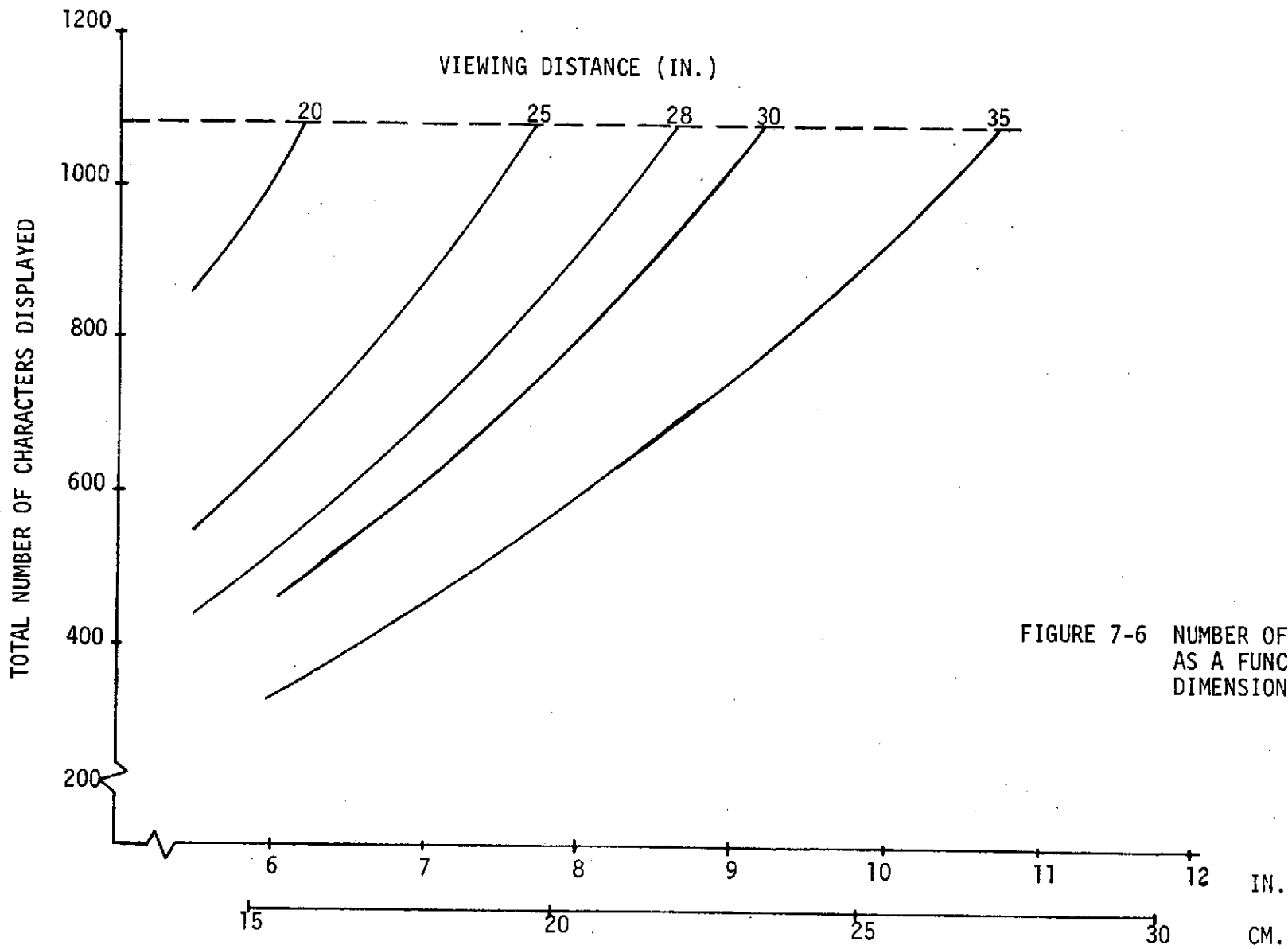


FIGURE 7-6 NUMBER OF DISPLAYED CHARACTER AS A FUNCTION OF MONITOR DIMENSION AND VIEWING DISTANC

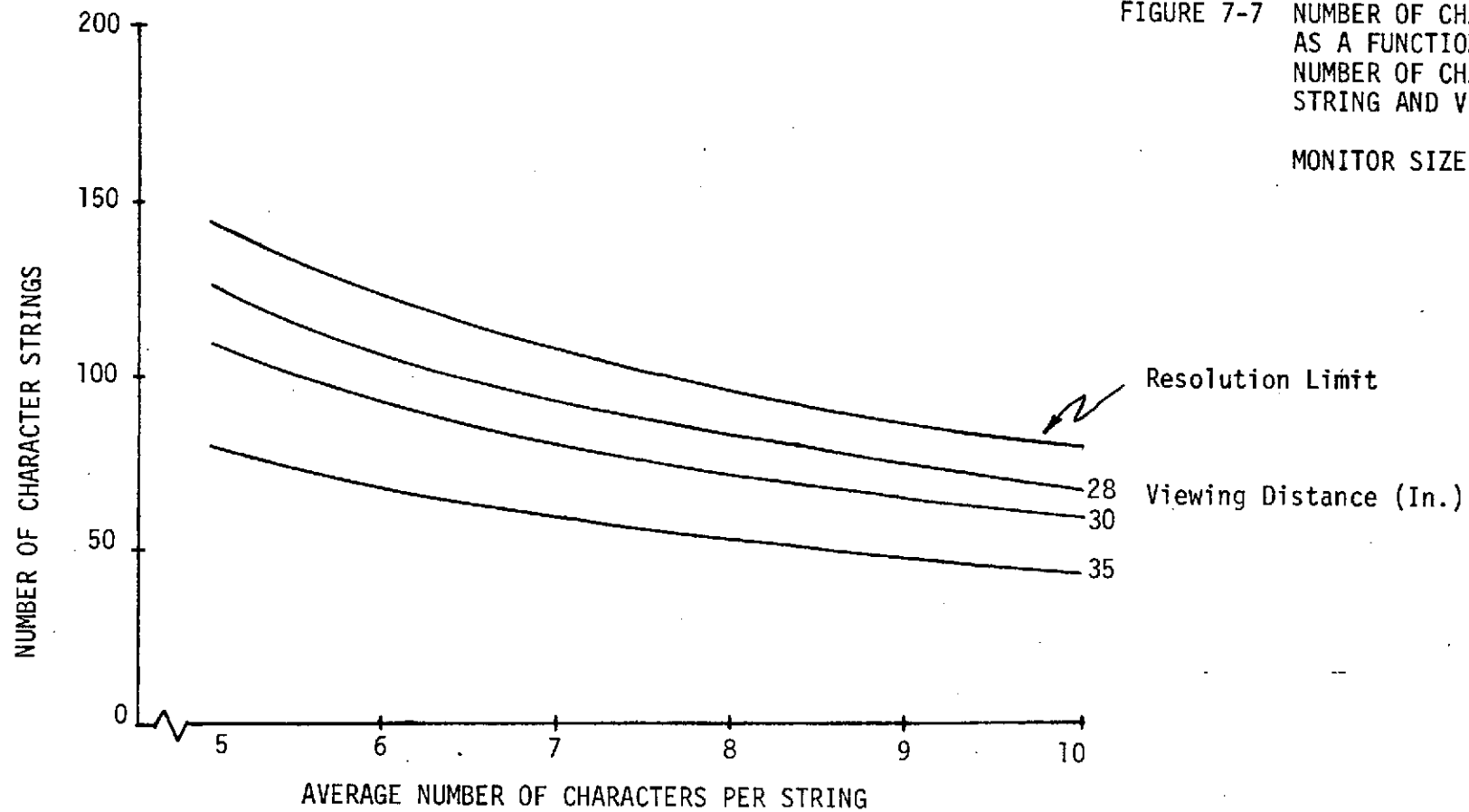
text. Furthermore, the total number of characters is equal to the number of character strings multiplied by the average string length. Eq. 7-1 may be modified to yield

$$N_s \cdot (C_s + 1) = \left[ \frac{M}{L} \right]^2 9041.59 \quad (7-2)$$

where  $N_s$  is the number of character strings and  $C_s$  is the average number of characters per string. Figure 7-7 shows the number of character strings which could be displayed on a 20 by 20 cm (8 by 8 in) monitor for various average string lengths and viewing distances. For example, at a 71 cm (28 in.) viewing distance about 67 character strings averaging 10 characters per string could be read. This corresponds to approximately one third of a typed page. This appears to be adequate for a single procedural step, for example.

The proposed monitor size of 20 by 20 cm ( 8 x 8 in ) therefore appears adequate for display of character arrays. This cannot be completely determined without reference to the exact nature of the printed material to be displayed during STS orbital operations. If a greater number of characters were required for simultaneous display, the monitor dimensions could be revised upward based on Figures 7-6 and 7-7. Based on currently available data, however, a monitor having a usable display area of 20 by 20 cm ( 8 x 8 in) appears to be suitable. Such a CRT size would be consistent in terms of tube length and volume with current constraints on the aft cabin panels. The recommended display size would be consistent with the following capabilities:

- . Detection of targets subtending .6 m rad. at the camera lens using a 7 deg. field of view and 71 cm (28 in) viewing distance.
- . Recognition of targets subtending 4.0 m rad. at the camera lens using a 7 deg. field of view and 71 cm (28 in.) viewing distance.



- . Detection of range rate of .06 ft/sec (.02 m./sec) of a 1 m. (3.3 ft) object at a range of 6.1 m. (20 ft.) using a 7 degree field of view and 71 cm (28 in) viewing distance
- . Recognition of arrays of 670 characters with standard vertical spacing or 930 characters with minimum spacing at a viewing distance of 71 cm (28 in).

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APPENDIX A  
VISUAL ACUITY DATA

## EXPERIMENT I - VISUAL ACUITY

The objective of experiment 1 was to determine the effects of video system parameters on operator performance in resolving a gap between two target objects

### Apparatus

The apparatus consisted of a task board, target objects, and a variable parameter television system as described in section II. The task board was placed normal to the visual (camera) axis and was painted to achieve an albedo of .4. The target plates were 3 X 4 inches in size and were painted with a flat finish to achieve an albedo of .3. The target-background contrast was therefore -.25. A micrometer mounted behind the task board enabled the experimenter to move the target plates apart, increasing the gap between them by increments of .25 mm. (approximately .01 inch).

### Experimental Design

Four independent variables were manipulated in experiment 1. These variables and their levels were as follows:

Field of view	10° FOV (horizontal) 25° FOV
Transmission Mode	Standard 4.5 MHz. Analog 4 Bit Digital 1 MHz Narrow Band
Signal-to-Noise Ratio	32 db 21 db 15 db
Gap Orientation	Vertical Horizontal

Five subjects attempted to perform the gap detection task at all possible combinations of levels of the independent variables. This entire design was replicated ten times - ten trials were administered to each subject under each

treatment combination. The four combinations of field of view and gap orientation were presented in blocks. The order of presentation of specific levels of these variables was randomized over subjects. Within each block, the order of presentation of combinations of the remaining variables was randomized.

The fixed parameters of the task included:

Incident Illumination - 70 ft. candles  
Aspect Ratio - 3:4  
Rate of change of separation - .25/mm./sec.  
No. of active lines - 335 lines from a 525 line system

The dependent measure was the size of the separation between the target plates at the point in time at which the subject judged the plates to be separated.

#### Procedure

The initiation of the video signal was under the control of the experimenter. The initial view presented to the subject showed the plates immediately adjacent (flush) to each other. The experimenter then manipulated the micrometer to control the separation of the plates in increments of .25 mm, one increment occurring each second. When the subject judged the plates to be separated, he signalled the experimenter by depressing a switch which also turned off the video display. At the end of each trial the experimenter recorded the separation at the point where the subject detected it, reset the target plates to the adjacent position, changed the video system levels, and then signalled the subject that a new trial was about to begin.

#### Results and Data Analysis

The raw data obtained were in terms of physical size of separation on the task board. Such a measure is quite specific to the apparatus employed and it was considered desirable to transform the data to visual angle at the operator's eye subtended by the target image displayed on the monitor. The basic relationships for this transformation are:

$$I = \frac{M \cdot S}{2R \cdot \tan \frac{\Omega}{2}} \quad \text{Equation 1.1}$$

where I = displayed separation dimension  
M = monitor width or height (in)      S = gap size (in) in object plane  
R = viewing range (in) object distance to camera  
Ω = optical field of view angular dimension (deg)

and

$$\lambda = \frac{3437.8I}{d} \quad \text{Equation 1.2}$$

where λ = visual angle (arc min.) subtended by eye  
I = displayed separation dimension  
d = viewing distance (in) subject to monitor  
3437.8 = arc min/radian

The required parameters of the experimental situation were as shown in Table 1-1.

TABLE 1-1. Experimental Parameters

Range from task board to camera R = 96 in.  
Viewing distance d = 21 in.

<u>Gap Orientation</u>	<u>Horizontal Field of View</u>	<u>Effective Field of View of Camera (Ω)</u>	<u>Displayed Size in the Direction of Separation (M)</u>
Vertical	10°	Ω V 10°	6.5 in
Vertical	25°	Ω V 25°	6.5 in
Horizontal	10°	Ω H 7.5°	5.125 in
Horizontal	25°	Ω H 18.75°	5.125 in

The resulting data on visual angle at detection were subjected to a five way analysis of variance. This analysis was performed on the means over the 10 replications per cell of the experimental design. A treatments by subjects model assuming all factors but subjects to be fixed was employed in conducting F tests. The resulting source table is shown as Table 1.2.

Table 1-2

ANALYSIS OF VARIANCE OF VISUAL  
ANGLE (MIN) FOR EXPERIMENT 1

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Gap Orientation (G)	1	2.167	2.167	1.86
Field of View (F)	1	186.606	186.606	37.01 **
Signal-Noise Ratio (R)	2	489.561	244.780	26.82 **
Transmission Mode (T)	2	36.397	18.198	13.71 **
Subjects (S)	4	82.826	20.707	---
G X F	1	.207	.207	< 1.00
G X R	2	2.816	1.408	4.32
G X T	2	5.667	2.834	7.93 *
G X S	4	4.662	1.165	---
F X R	2	10.326	5.166	1.55
F X T	2	7.172	3.586	3.36
F X S	4	20.168	5.042	---
R X T	4	90.294	22.735	13.29 **
R X S	8	72.997	9.125	---
T X S	8	10.618	1.327	---
G X F X R	2	0.135	0.067	< 1.00
G X F X T	2	0.404	.202	< 1.00
G X F X S	4	4.034	1.008	---
G X R X T	4	0.842	0.211	1.13
G X R X S	8	2.609	0.326	---
G X T X S	8	2.857	0.357	---
F X R X T	4	8.476	2.119	1.80
F X R X S	8	26.706	3.338	---
F X T X S	8	8.528	1.066	---
R X T X S	16	27.384	1.711	---
G X F X R X T	4	0.760	0.190	1.39
G X F X R X S	8	.589	0.074	---
G X F X T X S	8	4.289	0.536	---
G X R X T X S	16	2.969	0.186	---
F X R X T X S	16	18.811	1.176	---
G X F X R X T X S	16	2.191	0.137	---
TOTAL	179	1134.075	---	---

\* Significant at the .05 level

\*\* Significant at the .01 level

The effect of field of view was found to be significant at the .01 level. In terms of mean visual angle, 6.31 arc minutes were required with the 10 degree field of view and 4.28 arc minutes were required with the 25 degree field. This is a rather surprising finding since the field of view effect should be removed by conversion of the data to visual angle. One would expect the two field of view conditions to be equal. In fact, however, smaller angles were detectable with the 25 degree field.

It seems likely that the explanation involves the experimental apparatus. The maximum gap size which could be presented was 9 mm on the task board. Under the 25 degree condition, this maximum sometimes did not elicit a detection response and no further increase in gap size could be presented. When this occurred, the maximum value was taken as the detectable gap size. This state of affairs occurred much more often under the 25 degree condition than under the 10° condition and may, therefore, have limited the range of the dependent measure under the 25 degree condition. This effect would at least partially explain the observed result.

A second factor which might partially explain the field of view effect would result if the distribution of visual angles were markedly skewed in the positive direction under the 10 degree case. This possibility was evaluated by an analysis of variance performed on the common logarithm of visual angle. Such a transformation generally renders a skewed distribution more normal. The result of this analysis, however, was that the field of view effect remained significant at the .01 level and was in the same direction as stated previously. Skewness of the distribution, then, appears not to account for the observed result. It appears, therefore, that the explanation in terms of equipment limitations is preferable and that the observed effect should not be considered a feature of operator performance.

Both transmission parameters, transmission mode and signal to noise ratio were found to influence required visual angle at the .01 level. The main effect of transmission mode is depicted in Figure 1-1. The significance of observed differences in mean visual angle between the transmission modes was evaluated via Scheffé's procedure for judging all possible contrasts within a set of means (Winer, 1962). Because the Scheffé method is known to be extremely conservative (in terms of type II error) the .05 level was used for these comparisons. The result of this test showed the direct system to require smaller visual angles than either the narrow band or the digital systems. The difference between the latter two systems was not found to be significant.

The signal-to-noise ratio main effect is illustrated in Fig. 1-2. This graph suggests a critical level of signal-to-noise ratio in the vicinity of 20 decibels. Above this level, increases in signal-to-noise ratio appear to improve gap detection performance very little. These findings were confirmed by Scheffé test at the .05 level which showed significant differences between 15 decibels and 21 decibels but no difference between 21 and 32 decibels.

The interaction of transmission mode and signal-to-noise level was also found to be significant at the .01 level suggesting that these variables exhibit joint effects. The relationships are depicted in Fig. 1-3. To assess the significance of these differences, a separate Scheffé test at the .05 level was conducted on the differences between transmission mode means at each level of signal-to-noise ratio. The results indicated no reliable differences between transmission modes at signal-to-noise levels of 21 or 32 decibels. At 15 decibels, however, all three transmission modes were found to differ at the .05 level - that is, the direct mode was found to require smaller visual angles than the narrow mode which, in turn, required

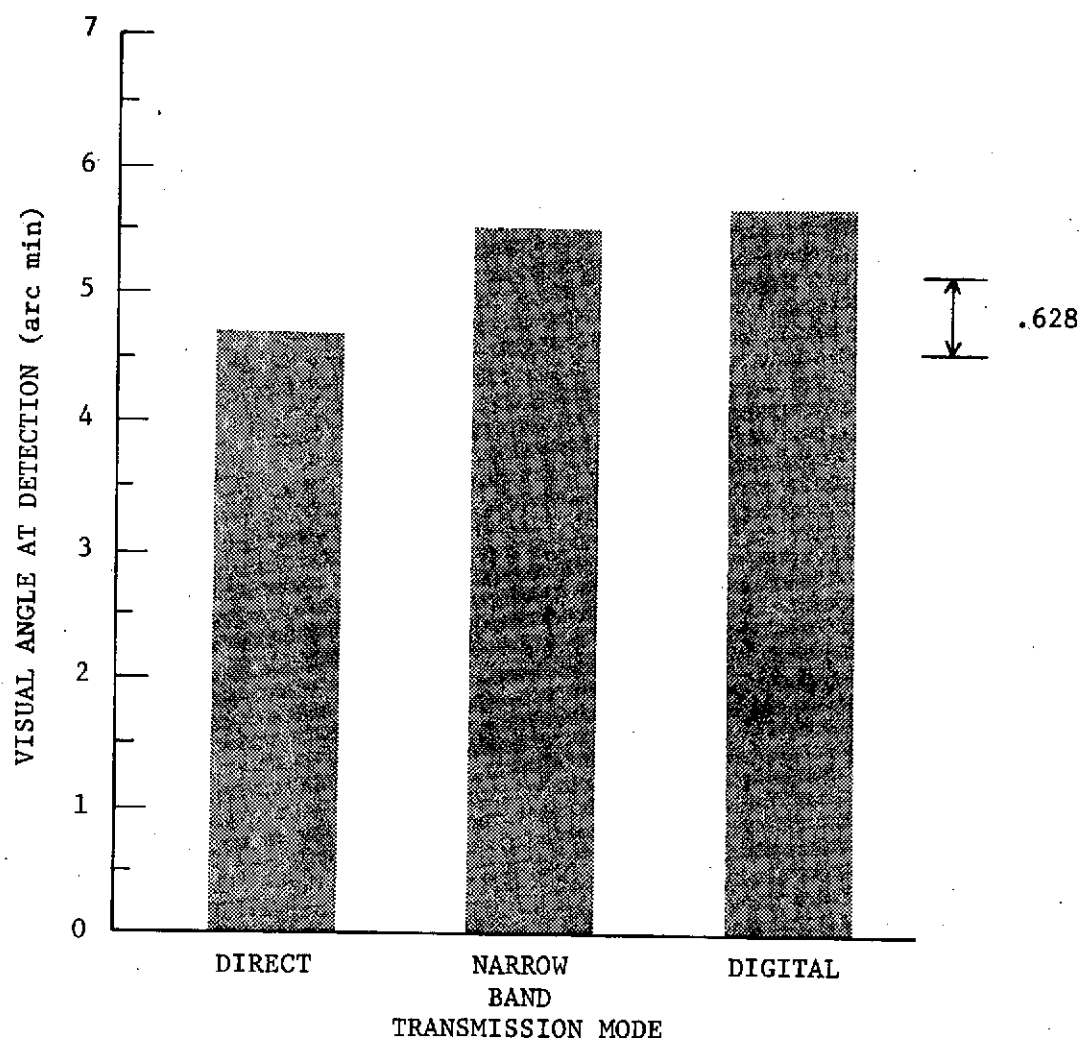


Figure 1-1 MEAN VISUAL ANGLE (arc min) AT DETECTION AS A FUNCTION OF TRANSMISSION MODE

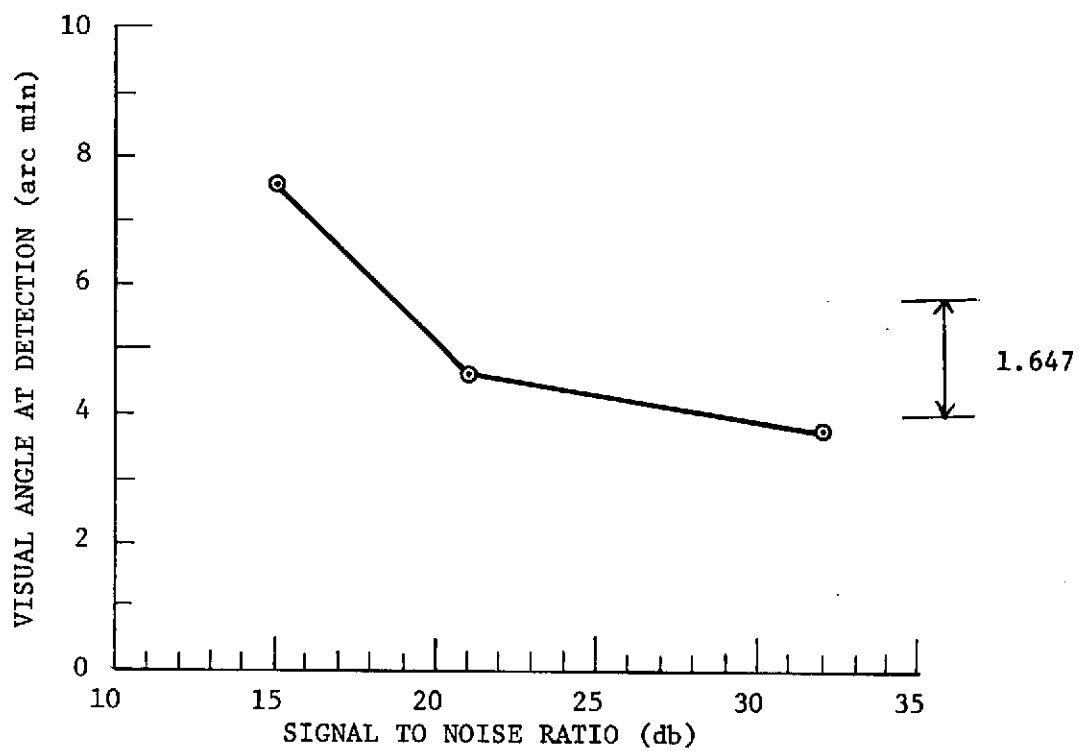


Figure 1-2. MEAN VISUAL ANGLE (arc min) AT DETECTION AS A FUNCTION OF TV SIGNAL TO NOISE RATIO (db)

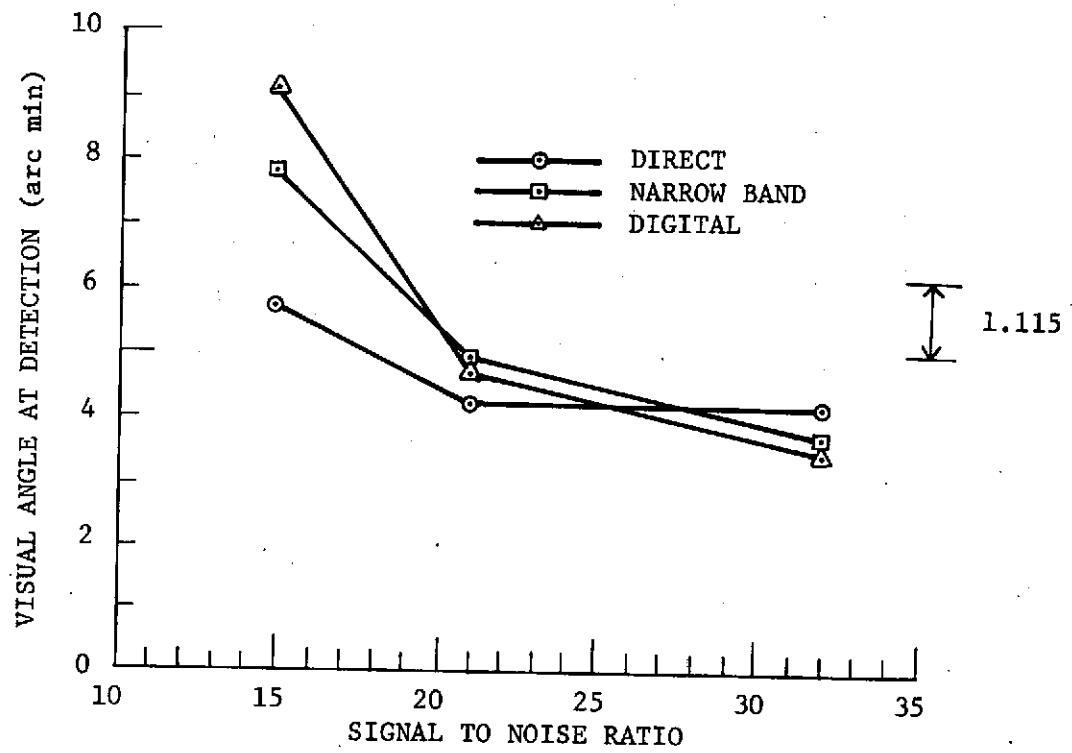


Figure 1-3. MEAN VISUAL ANGLE (arc min) AT DETECTION AS A FUNCTION OF TRANSMISSION MODE AND SIGNAL TO NOISE RATIO (db)

smaller angles than the digital mode when the signal-to-noise ratio was fixed at 15 decibels. The results suggest that transmission mode influences resolution performance only at low signal-to-noise levels (i.e. less than 20 decibels).

While vertical vs. horizontal orientation of the gap per se did not influence performance, this variable did interact with transmission mode as is shown in Fig. 1-4. Since the interaction was significant at the .05 level, a Scheffé test at the .10 level was performed on vertical vs. horizontal gap orientation at each level of transmission mode. The results indicated no effect of gap orientation for the direct or narrow band systems. Under the digital mode, however, horizontal gap orientation was found to require larger visual angles on the average than did vertical orientation. It was observed that in the vertical orientation and in the digital mode that the digital information appeared to "line up" on the target gap so as to structure a line along the gap. This "lining up" of digital information was not noted with the gap in the horizontal position.

While the mean visual angle for resolution is a useful figure of merit in comparing systems, it is difficult to use it in projecting operator/system performance in real world situations. It would be convenient for this purpose to examine the function relating probability of detection given that the operator is viewing a gap having a particular visual angle. Denote this quantity by  $a_\lambda$ , where  $\lambda$  represents gap size. The probability distribution of gap visual angle at detection is denoted  $P_\lambda$ . This function was readily available from the data.

Since the experimental procedure involved strictly ascending series where the gap was increased until it could be detected:

$$P_\lambda = a_\lambda \prod_{i=1}^{k-1} (1-a_i)$$

Equation 1.3

where  $i = \{1, \dots, k\}$  indexes various values of  $\lambda$

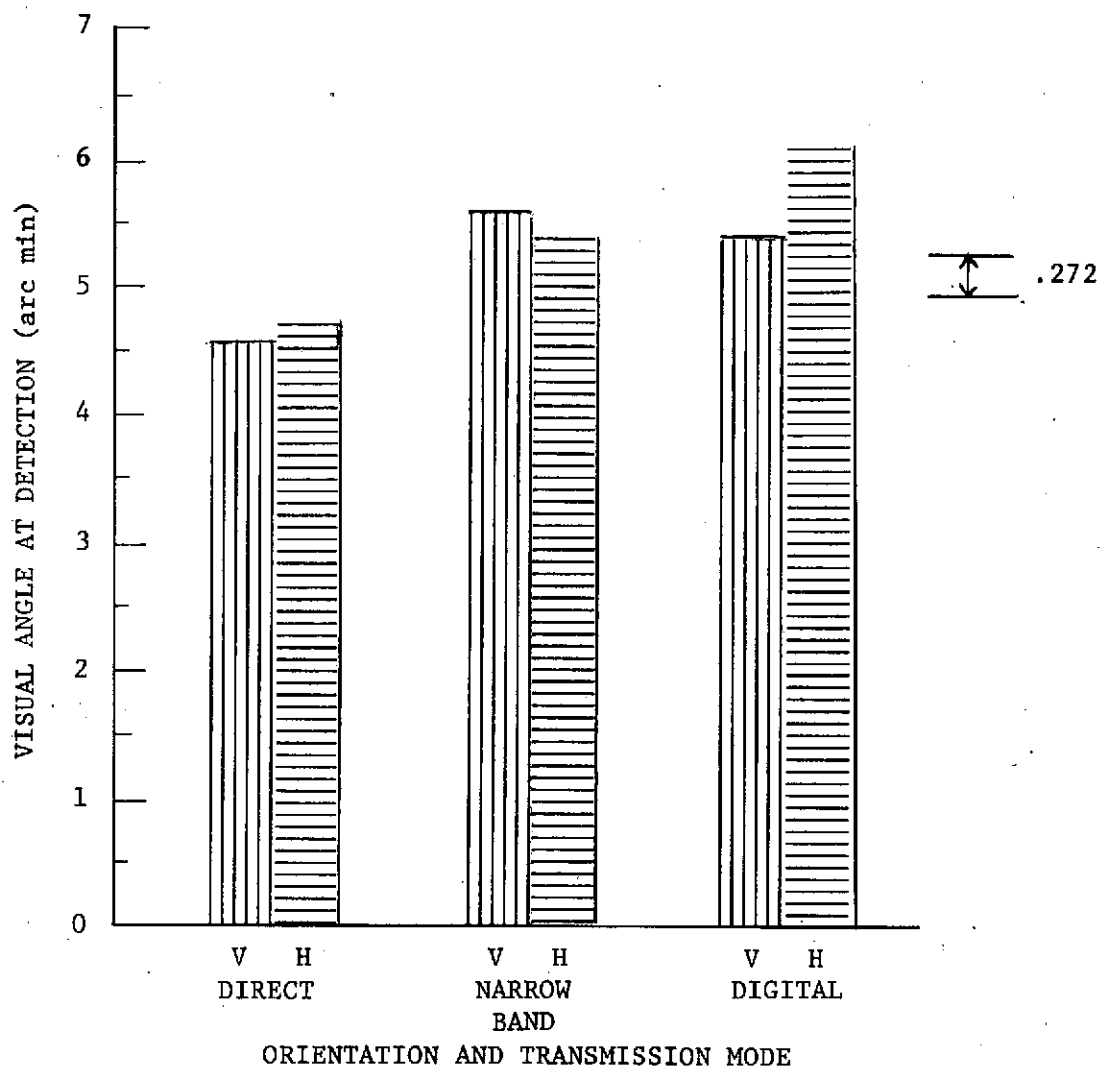


Figure 1-4. MEAN VISUAL ANGLE (arc min) AT DETECTION AS A FUNCTION OF GAP ORIENTATION AND TRANSMISSION MODE

and:

$$a\lambda = P\lambda \left[ \prod_{i=1}^{k-1} (1-a_i) \right]^{-1} \quad \text{Equation 1.4}$$

Eq. 1.4 as a function of visual angle was solved for combinations of signal-to-noise ratio and transmission mode. Since the analysis of variance results indicated an effect of transmission mode only under the 15 decibel signal-to-noise condition, the detection probability analysis was carried out under the following conditions.

<u>Signal-to-noise ratio (db)</u>	<u>transmission mode</u>
15	direct
15	narrow band
15	digital
21	data collapsed over transmission mode
32	data collapsed over transmission mode

The resulting functions showing detection probability ( $a\lambda$ ) as a function of visual angle ( $\lambda$ ) are depicted in Fig. 1.5. This figure may be used to determine the probability gap detection given a particular visual angle under the various transmission parameters. Conversely, the required visual angle for a required level of performance may be determined. Table 1-3 presents the required visual angle for detection probabilities of .6 and .9 across the various systems.

Table 1-3. Required Visual Angle (arc minutes) for Detection Probabilities of .6 and .9 Under Various Transmission Parameter Conditions

<u>Signal-to-Noise Ratio (db)</u>	<u>Transmission Mode</u>	<u>Detection Probability</u>	
		<u>.6</u>	<u>.9</u>
15	direct	7.25	9.50
15	narrow band	7.75	10.50
15	digital	11.25	19.25
21	-----	5.30	6.80
32	-----	3.75	5.00

To examine the impact of these data on system design decisions, equations 1.1 and 1.2 may be combined yielding:

$$\lambda = \left[ \frac{3437.8}{d} \right] \left[ \frac{M.S}{2R \cdot \tan \frac{\Omega}{2}} \right] \quad \text{Equation 1.5}$$

Notice that the units for S and R are arbitrary so long as both variables are measured in the same units. Substituting  $\lambda$  values from Table 1-3 (or the corresponding values for other levels of detection probabilities) in eq. 1.5 yields a relation between system parameter levels which must hold to achieve the desired performance level. Figure 1-6 illustrates the procedure. Here a 10° field of view, 21 inch monitor-to-eye distance and a monitor dimension of 7 inches were assumed. The .9 detection probability data from Table 1-3 were then substituted in eq. 1.5 permitting projection of maximum detection range as a function of separation for the various transmission (mode levels). There are many other ways of solving eq. 1.5 in conjunction with the performance data presented in Fig. 1-6. Many of these analyses should yield information on the impact of system parameter values on performance. In performing these analyses, it should be understood that many variables which were held constant here influence operator/system

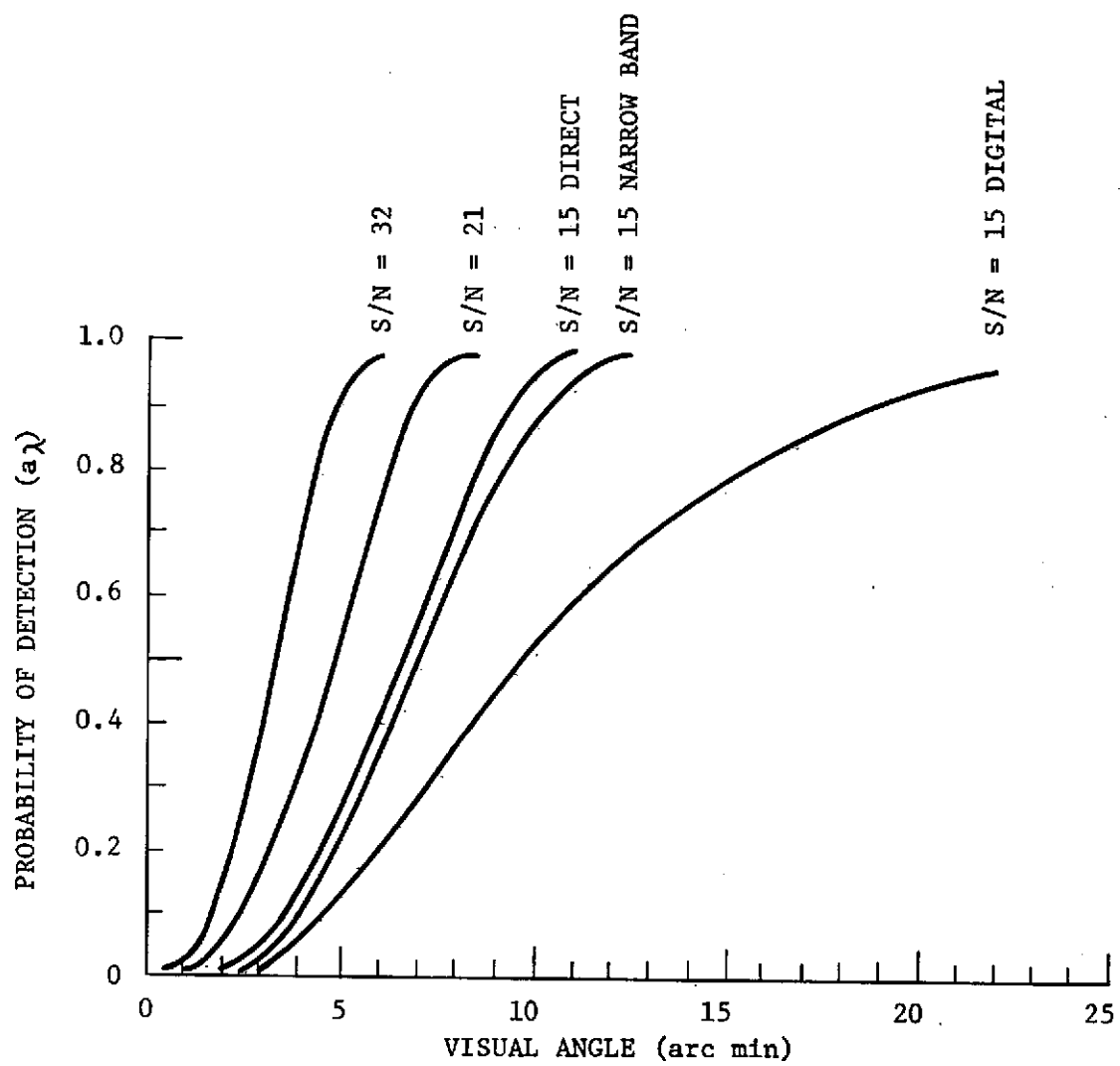


Fig. 1-5. Detection Probability as a function of visual angle

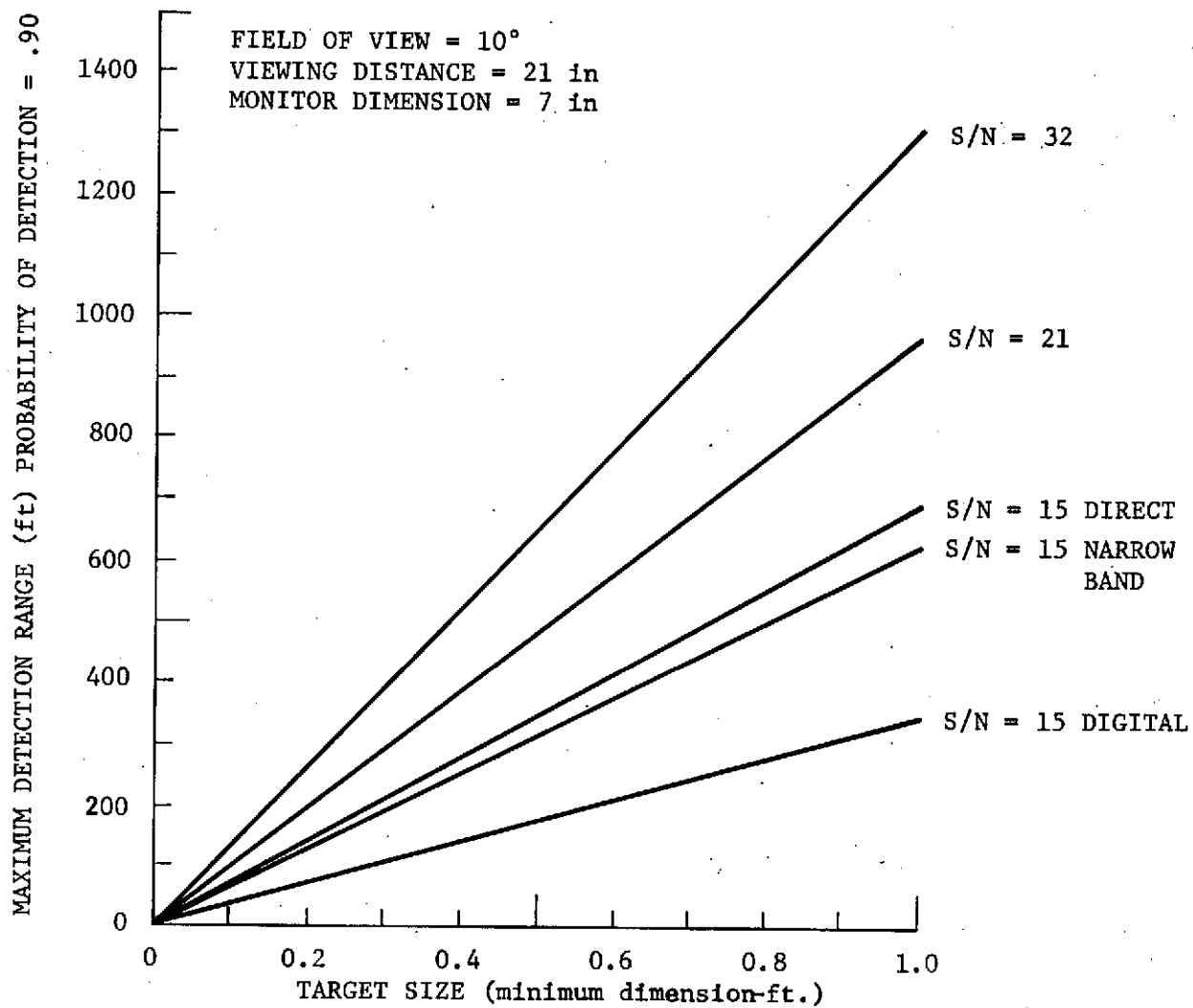


Figure 1-6. CALCULATED MAXIMUM DETECTION RANGE (ft) AS A FUNCTION OF SEPARATION, SIGNAL-TO-NOISE RATIO, AND TRANSMISSION MODE FOR PROBABILITY OF DETECTION = .90.

performance. The data presented here will hold only under the stated test conditions. For instance, these data should not be used for contrast conditions other than those employed in the current investigation.

## APPENDIX B

### FORM DISCRIMINATION DATA

### EXPERIMENT NUMBER 3 - FORM DISCRIMINATION

The objectives of this experiment were to determine the effects of various transmission characteristics and target-background contrast conditions on an observer's ability to recognize target shapes.

#### Apparatus

The experimental apparatus consisted of a task board with a background reflectivity of .5 mounted perpendicular to the visual (camera) axis. Also, two sets of six targets, each set consisting of a circle, an ellipse, a triangle, a square, a rectangle and a hexagon each of which measured one inch along the widest axis. The triangle was equilateral and the rectangle had a 3:4 aspect ratio. One set of six targets was painted to a reflectivity of .4, the other to a reflectivity of .7.

#### Experimental Design

The independent variables included the following:

4 transmission parameters

- 1) Direct with 32 db S/N
- 2) Direct with 15 db S/N
- 3) Digital (4 Bit) with 15 db S/N
- 4) 1 MHz<sub>2</sub> Narrow Band with 15 db S/N

2 target background contrasts

- 1) .4 targets on .5 background
- 2) .7 targets on .5 background

6 target shapes

- 1) circle
- 2) ellipse
- 3) triangle
- 4) square
- 5) rectangle
- 6) hexagon

The dependent variables were:

- 1) Accuracy of shape recognition
- 2) Time to recognize shape

The control variables were set at the following levels:

- 1) Target illumination - 70 ft. candles
- 2) Vertical resolution - 525 lines, ~ 350 active lines
- 3) Maximum time allowed - 1 minute
- 4) Average rate of change of field of view - to allow a 1/32 inch increase in target size on monitor every 2 seconds.

Each of the five subjects used was screened for 20-20 vision. Each subject was tested for all combinations of conditions in this experiment. The four transmission parameters and the six target shapes were presented to each subject in randomized combinations. The sequence of target background conditions was counterbalanced among subjects. All combinations of conditions were replicated three times for each subject under each contrast condition for a total of 144 trials per subject.

#### Procedure

Each of five subjects was presented with a test shape at a maximum field of view (25°) and asked to report its shape. The camera field of view was decreased to enlarge the target image size on the video monitor. The target image was increased by 1/32 inch increments until the subject correctly identified the shape. The time period for viewing between incremental steps was two seconds. When the subject judged that he had identified the shape, he pushed a response key which terminated the video image. The experimenter noted the reported shape of the figure and the size of the figure when correctly identified, as well as the subject's response time. The experimenter then proceeded to the next trial.

#### Results

Two dependent measures were scored in experiment 3 - response time in seconds and target size at recognition in units of 1/32 inch on the TV monitor. Both measures were subjected to a four way analysis of variance. Prior to this analysis, means were computed over the three replications. These cell means were subjected to analysis of variance assuming a treatments by subjects design with

all factors except subjects fixed. It was found that both analyses reached the same conclusions in terms of significant effects. This result would be expected since, according to the experimental procedure, time and target size increased linearly until the target was recognized. In view of this correlation between the measures, analysis of response time would not be expected to yield much additional information relative to the target size analysis. Accordingly, only target size at recognition was subjected to further statistical analyses. The source table for the analysis of target size is shown in Table 3-1. Table 3-1 shows figure type to exert a significant effect on target size at recognition ( $=.01$ ). The relationship is depicted in Figure 3-1. A Scheffé test at the .05 level was performed and the critical difference for comparisons between means is shown as a vertical bar in Figure 3-1. Any difference which equals or exceeds this value is significant at the .05 level. The results suggest that the discrimination between hexagon and circle is a difficult one. No significant differences between the remaining four figures were detected. The implication would appear to be that discrimination of hexagonal and circular shapes by the operator should be avoided in selecting markings and component shapes. It would also appear that angular and/or elongated shapes provide better cues for recognition.

The main effect of the transmission condition variable was also found to be significant at the .01 level. These data were, therefore, tested by the Scheffé procedure at the .05 level. The results are illustrated in Figure 3-2. The critical difference between means for the .05 level Scheffé test is shown as a vertical bar. The 32 db direct transmission condition was found to yield lower recognition times than any of the 15 db conditions ( $\alpha < .05$ ). Within the 15 db condition, the difference between digital and narrow band transmission was found to be significant at the .05 level. It should be noted that this finding differs from that of experiment 1 in which the transmission modes were differentiated at the 15 db signal to noise level. Evidently, the effect of transmission mode depends to some extent on the task being performed.

TABLE 3-1

## ANALYSIS OF VARIANCE OF TARGET SIZE FOR TEST 3

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Figure (A)	5	155.680	31.136	15.58 <sup>†</sup>
Contrast (C)	1	0.167	0.167	<1.00
Transmission/Signal-to- Noise Ratio (M)	3	83.547	27.849	26.70 <sup>†</sup>
Subjects (S)	4	53.396	13.349	--
A x C	5	4.476	0.895	1.54
A x M	15	59.085	3.939	7.56 <sup>†</sup>
A x S	20	39.955	1.998	--
C x M	3	7.553	2.518	6.81 <sup>†</sup>
C x S	4	8.905	2.226	--
M x S	12	12.516	1.043	--
A x C x M	15	18.407	1.227	3.71 <sup>†</sup>
A x C x S	20	11.607	0.580	--
A x M x S	60	31.262	0.521	--
C x M x S	12	4.437	0.370	--
A x C x M x S	60	19.870	0.331	--
TOTAL	239	510.863	--	--

\*Significant at the .05 level

\*\*Significant at the .01 level

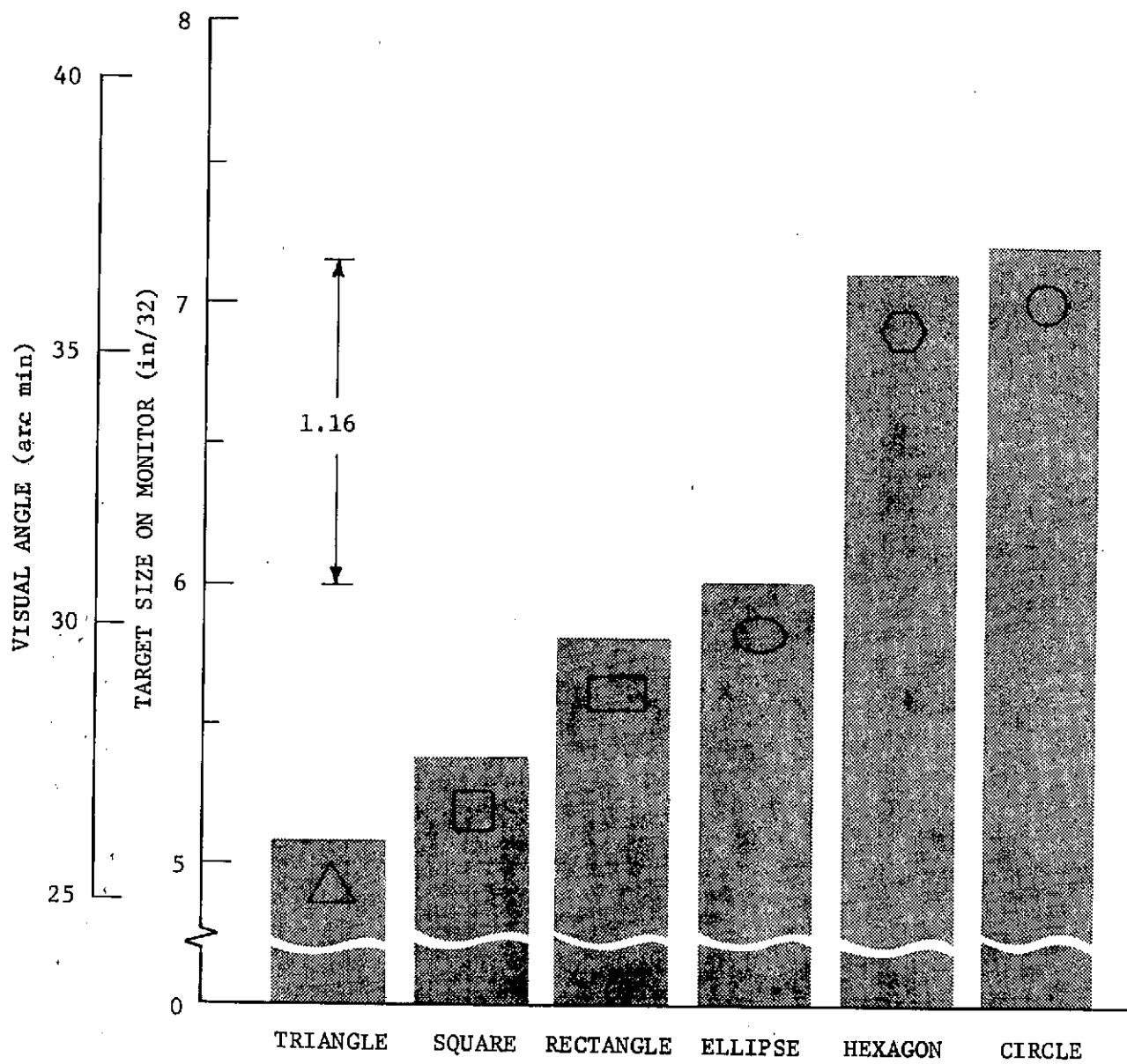


Figure 3-1. TARGET SIZE AT RECOGNITION AS A FUNCTION OF FIGURE TYPE

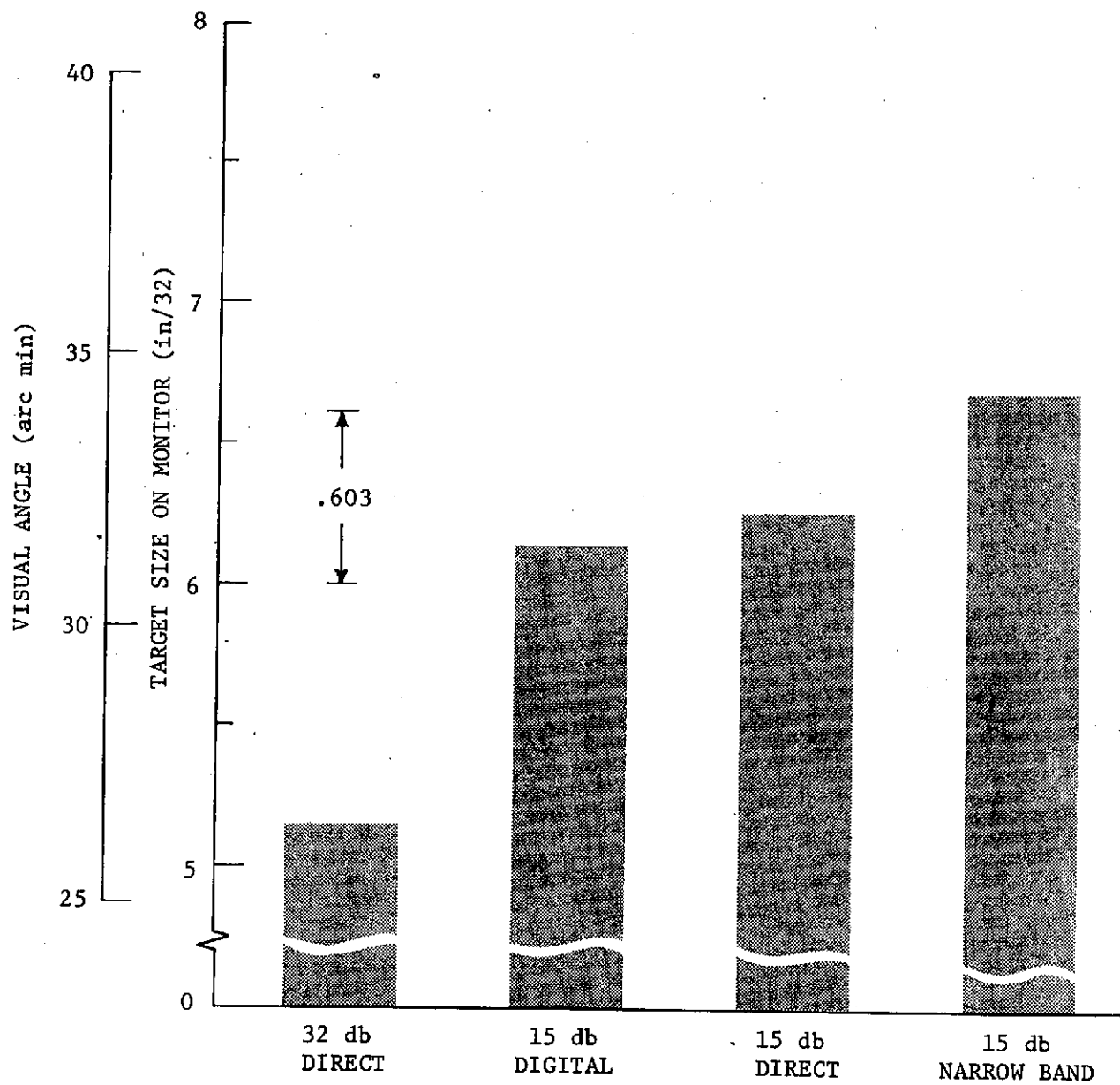
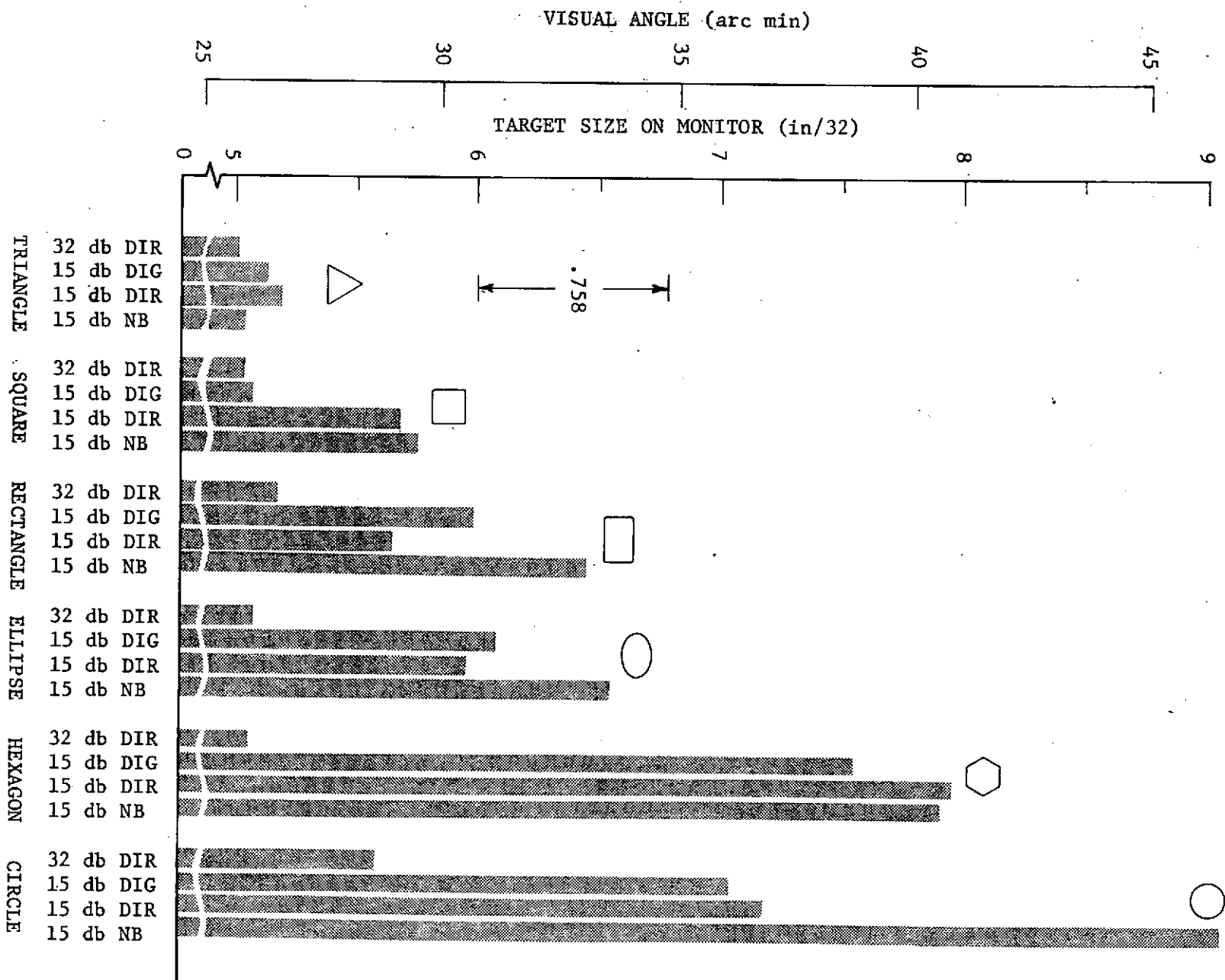


Figure 3-2 TARGET SIZE AT RECOGNITION AS A FUNCTION OF TRANSMISSION MODE AND SIGNAL-TO-NOISE RATIO

The interaction of figure type and transmission condition was also found to be significant at the .01 level indicating joint effects of these variables. The data along with the critical difference for a .05 level Scheffé test of transmission condition means within a particular figure type are shown in Figure 3-3. These data show no effect of transmission condition for the triangle or square. Under the remaining figure types, the significant comparisons are generally between the 32 db direct condition and all other transmission conditions. For two figures, the rectangle and the circle, however, the transmission modes at the 15 db signal-to-noise ratio level do become significantly different. An important finding illustrated in Figure 3-3 is that very little effect of the various figure types is noted for the 32 db direct transmission condition. The conclusion that recognition of hexagon and circle shapes should be avoided is therefore warranted only in the case of the 15 db signal-to-noise ratio level.

Although target background contrast was not found to exert a significant main effect, it did interact with transmission condition. The interaction was found to be significant at the .01 level. The effect is depicted in Figure 3-4 which also shows the .05 Scheffé critical difference for comparison of transmission condition from the general trend of the data. While the other three transmission conditions show some small degree of improvement (reduction in required target size) as a result of increased contrast, the opposite effect is noted for the 15 d narrow band condition. This finding derives from a more complex set of effects associated with the figure type by contrast by transmission condition interaction which was also found to be significant at the .01 level. Examination of this effect showed that the data for circle and hexagon shapes contribute to the significance of the contrast by transmission condition interaction. An exceed-

Figure 3-3 TARGET SIZE AT RECOGNITION AS A FUNCTION OF TYPE OF FIGURE, TRANSMISSION MODE, AND SIGNAL-TO-NOISE RATIO



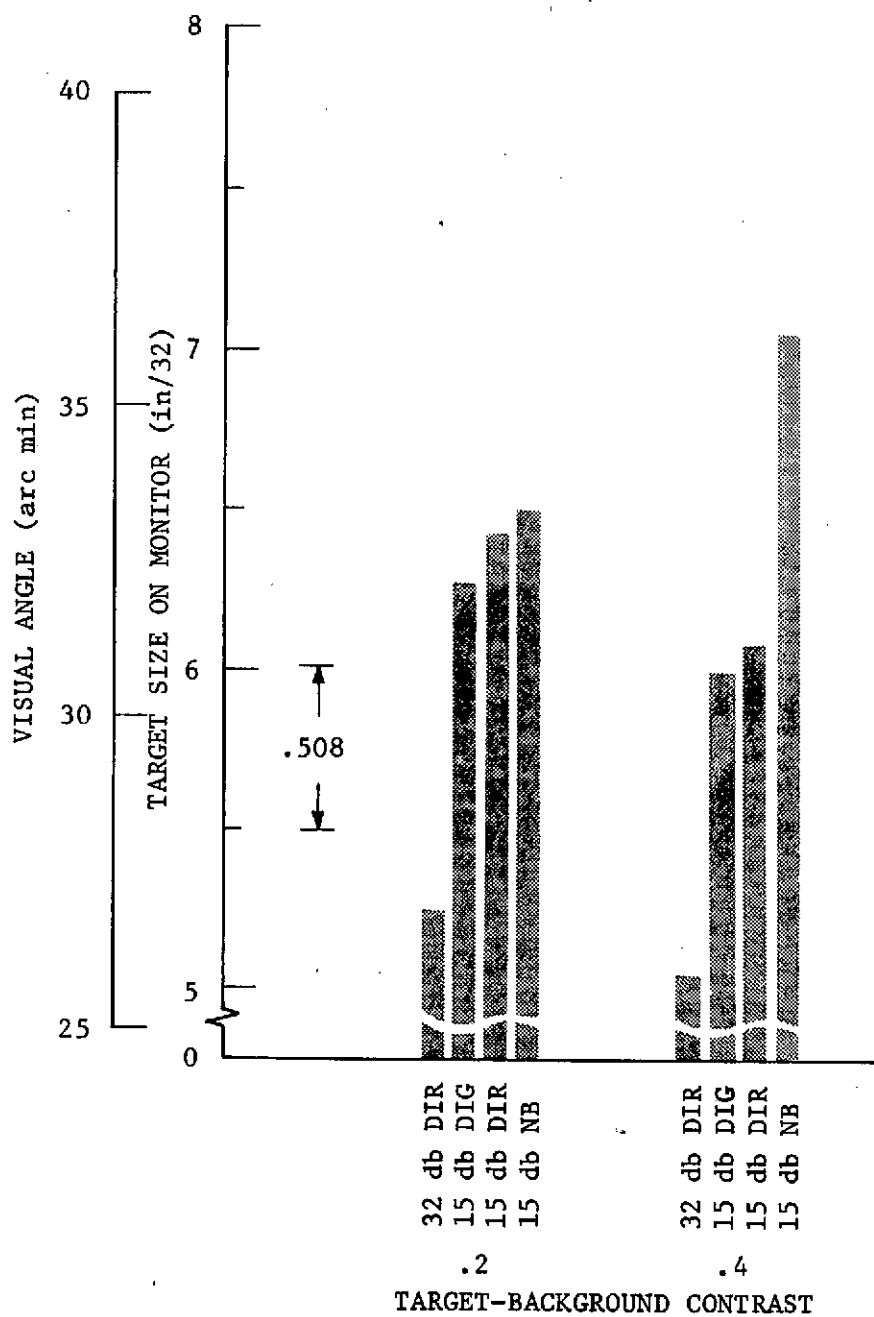


Figure 3-4 TARGET SIZE AT RECOGNITION AS A FUNCTION OF TARGET-BACKGROUND CONTRAST, TRANSMISSION MODE, AND SIGNAL-TO-NOISE RATIO (db)

ingly complex series of relationships exist between transmission mode and contrast within the data collected using the circle and hexagon shapes and the 15 db signal-to-noise level. It appears that whether the circle or the hexagon is more difficult to recognize depends on the joint combination of transmission mode and contrast.

This finding lends further support to the notion that recognition of circle and hexagon shapes should not be required of the operator if the signal-to-noise ratio level is low - i.e., in the vicinity of 15 db. Perhaps the best way to summarize these results is to say that the effect of system parameters on performance in recognizing circles and hexagons under low signal-to-noise ratio levels is complex - design principles cannot be simply stated because they would depend on contrast which may not be under the designer's control. For higher signal-to-noise ratios (perhaps above 20 db), regardless of figure type and for the figures other than hexagons and circles under low signal-to-noise ratios, the data follow more simple trends and can be more easily incorporated into design principles.

## APPENDIX C

### RANGE RATE DETECTION DATA

#### 4.1 Teleoperator Visual System Evaluation Laboratory Experiment B<sub>2</sub> - Motion Detection of a Target Object

The objective of this experiment was to determine the effects of alternative visual display aid conditions on the human operator's ability to detect fore/aft motion of a target object.

##### Apparatus

The task area, task board and target motion generator used in this experiment are described in the Target Motion Generator section of this report. Additionally, a round target (15.2 cm diameter) was affixed to the end of the TMG. This target was painted to a reflectivity of .7. The target in this case was a thin aluminum disc mounted on the TMG and on axis with the camera such that a true three dimensional target was not necessary.

A single Cohu Model 2000 mono TV system was employed in this experiment, and the subject's view was displayed on a single Conrac monitor. The monitor face could be outfitted with either of two reticles shown in Fig. 1. These reticles were acetate overlays affixed directly to, and centered on, the monitor face.

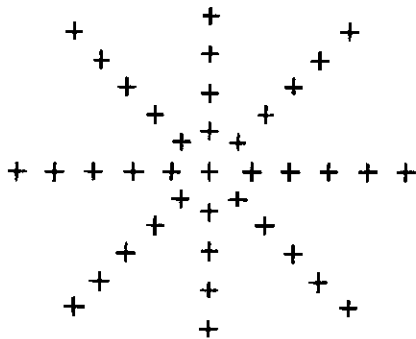
##### Independent Variables and Experimental Design

The independent variables studied were:

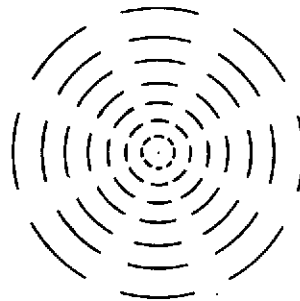
- . Target motion direction
- . Initial range
- . Range rate
- . Reticle conditions

To establish initial range conditions, the apparatus was adjusted to present a displayed image size equal to that of a BRM satellite at ranges

CANDIDATE  
RETICLE 1



CANDIDATE  
RETICLE 2



The third viewing condition was an  
unaided, without reticle, condition.

FIGURE 16. Candidate Reticle Formats Used for Motion Detection

of 20 or 30 feet. This established a simulated target dimension of 3 feet (the diameter of the BRM). Image size on the monitor is given by:

$$I = \frac{M}{2 \tan (\alpha/2)} \frac{T}{R} \quad (1)$$

Where I = displayed image size } same units  
M = monitor dimension }  
T = target dimension } same units  
R = camera to target range }  
 $\alpha$  = angular F.O.V. dimension

For a particular TV system at a fixed optical zoom setting:

$$\frac{M}{2 \tan (\alpha/2)} \quad (2)$$

is fixed and may be replaced by a constant K, so that

$$I = \frac{KT}{R} \quad (3)$$

The rate of change of image size is given by the first derivative with respect to time of eq. (3)

$$\dot{I} = \frac{dI}{dt} = \frac{R \cdot \frac{dKT}{dt} - KT \cdot \frac{dR}{dt}}{R^2} \quad (4)$$

$$\dot{I} = \frac{-KTR}{R^2} \quad \text{for } R \text{ a constant} \quad (5)$$

The real world conditions simulated were the following:

- . Target - end view of a BRM satellite (3 ft target dimension)
- . Angular field of view -  $20^\circ$  (diagonal)
- . Monitor dimension - 7.75 in (diagonal)
- . Initial range - 20 or 30 ft
- . Viewing time - 2 sec

To simulate these conditions, the image size rate of change profiles for the stated conditions and various values of  $\dot{R}$  were calculated by means of eq. (5). Range, target size, field of view, and TMG rates were chosen to produce the desired profiles during the 2 sec. viewing time period. To characterize each level of image size rate of change, the mean rate during the viewing time period was employed since regarding  $\dot{I}$  as a constant results in only a small percent error. That is, the relationship between image size and time does not depart appreciably from linearity over the time interval employed. The mean rate of change of image size over a time period  $\Delta t$  is given by:

$$\bar{\dot{I}} = \frac{-KTR}{R_0(R_0 + \dot{R}\Delta t)} \quad (6)$$

Where  $R_0$  = initial range

The independent variables manipulated in the experiment included the following:

- . Reticle condition - no reticle, cross hatch reticle, concentric ring reticles as illustrated in Fig. 1.
- . Image size rate - under each reticle condition, five positive image rates, five negative image rates, and one condition of no change were selected as shown in Tables 8 and 9.
- . Initial range - simulated 20 or 30 ft.

The dependent variable measured was probability of error in judging the displayed rate to be positive, negative, or zero.

The control variables were set at the following levels:

- . Target lighting - 100 foot candles  
± 1 fc over the entire train of travel for the TMG
- . Transmission parameters - 4.5 MHz  
direct transmission with 32 db signal to noise ratio

- . Target parameters

- shape - circular
  - size - 15.24 cm diameter
  - reflectivity - .7

- . Subject's viewing time of target - 2.0 seconds

- . TV system parameters - peak white sensitivity at .8 reflectivity

Each of five subjects was screened for normal vision using the standard orthorator visual tests. Each subject received all combinations of conditions. The presentation of rates, ranges, and directions of travel were randomized. The 2 reticle conditions and one no-aid condition were run in blocks of 22 trials, which were counterbalanced among subjects, so that 22 trials under one aid condition were run before changing to another aid condition. There were two replications for all trials for each subject. This yielded 132 trials for each of 5 subjects ( 5 rates x 2 directions x 2 initial ranges x 3 aid conditions x 2 replications + 12 combinations where rate and direction were zero). Total trials run for this experiment were 660 trials.

#### Procedure

Prior to any experimental run, all equipment in the Visual System Laboratory was calibrated by the experimenter. This assured a constant set of conditions between subjects. The experimenter then selected the appropriate display aid and fitted it to the monitor face (see Fig. 16).

At the time of an experimental run the subject was seated in front of the test TV monitor and its position was adjusted so that it was 21 inches from the bridge of the subject's nose and 15° below the horizontal plane. A set of prepared instructions was read to the subject and he was asked if he understood the task requirements. When the subject fully understood

his role in the experiment, the experimenter left the subject's area and went into the task area to prepare for the first set of trials.

The experimenter set the TMG translation arm to its center position, as indicated by scribes on the arm and power gear. The experimenter then manipulated the camera's zoom control to set the initial range condition to simulate either 20 or 30 feet according to the experimental plan data sheet. From the data sheet, the experimenter also selected the conditions for other independent variables, the direction and rate of translation. These were controlled by a multi-rotational knob which indicated motor speed settings which would produce the appropriate average changes in displayed image size as a function of direction of travel, the details of which are outlined in Tables 9 and 10. If the data sheet indicated an increase in range condition was to be the trial, he set the TMG translation arm forward of the center position on the arm before starting the trial. This allowed any "chatter" in the arm, due to an abrupt start, to be nulled out prior to the time the TV image was displayed to the subject. When the scribes on the arm and power gear travelled to the center position the experimenter would call out "ready" and press the subject's TV image control switch which instantly gave a TV image on the monitor in the subject's station and activated a digital timer in the experimenter's station. The subject was allowed a 2.0 second view of the scene, at which point the experimenter would activate the control switch and terminate the subject's TV image. The experimenter recorded the subject's response and set up the conditions for the next trial.

### Results

Since the independent variable, image size rate of change, was nested in reticle condition, the total data matrix could not be subjected to a

TABLE 9. Displayed Mean Rate of Change of Image Size Used With Reticles

<u>INITIAL TARGET RANGE (FT)</u>	<u>MEAN RATE OF CHANGE OF IMAGE SIZE FOR THE 2 SECOND VIEWING INTERVAL (IN/SEC)</u>	<u>CORRESPONDING SIMULATED RANGE RATE (FT/SEC)</u>
20	-.021	+.129
20	-.016	+.098
20	-.011	+.067
20	-.006	+.037
20	-.001	+.006
20	0.000	0.000
20	+.001	-.006
20	+.006	-.036
20	+.011	-.066
20	+.016	-.096
20	+.021	-.126
30	-.021	+.292
30	-.016	+.222
30	-.011	+.152
30	-.006	+.082
30	-.001	+.014
30	0.000	0.000
30	+.001	-.014
30	+.006	-.082
30	+.011	-.149
30	+.016	-.215
30	+.021	-.281

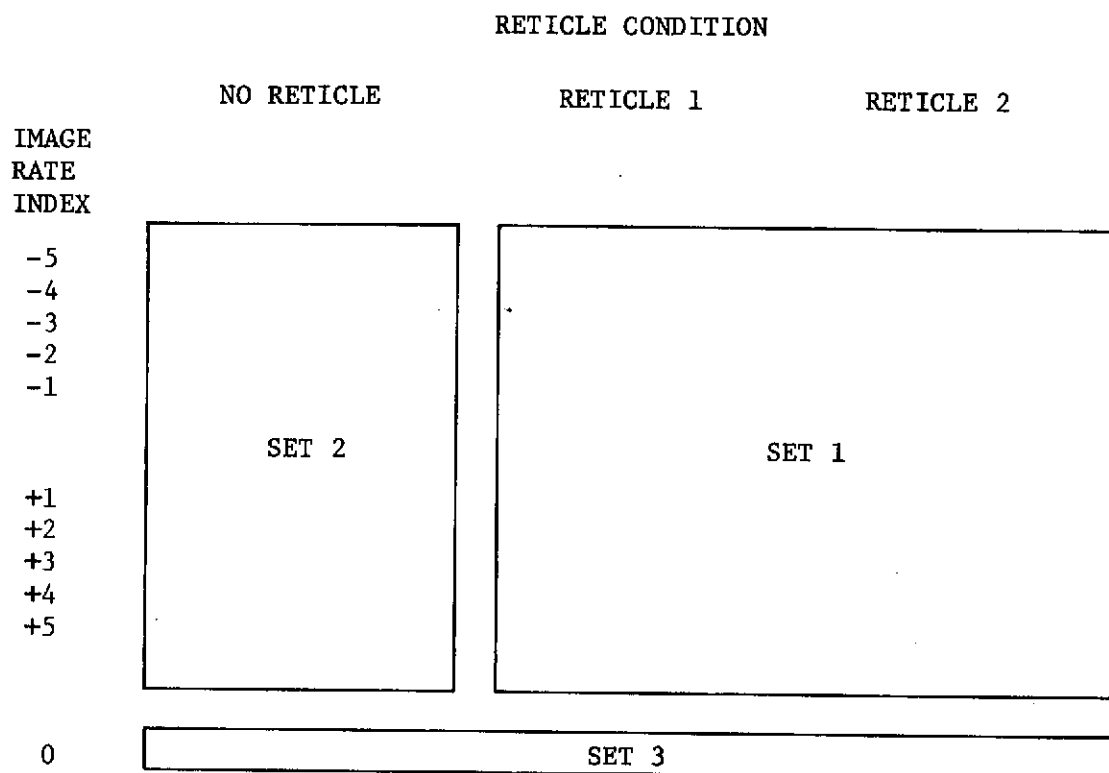
TABLE 10. Displayed Mean Rate of Change of Image Size Used With No Reticle Condition

<u>INITIAL TARGET RANGE (FT)</u>	<u>MEAN RATE OF CHANGE OF IMAGE SIZE FOR THE 2 SECOND VIEWING INTERVAL (IN/SEC)</u>	<u>CORRESPONDING SIMULATED RANGE RATE (FT/SEC)</u>
20	-.070	+.444
20	-.055	+.345
20	-.040	+.249
20	-.025	+.154
20	-.010	+.061
20	0.000	0.000
20	+.010	-.061
20	+.025	-.149
20	+.040	-.237
20	+.055	-.323
20	+.070	-.407
30	-.070	+1.021
30	-.055	+.790
30	-.040	+.567
30	-.025	+.349
30	-.010	+.138
30	0.000	0.000
30	+.010	-.135
30	+.025	-.334
30	+.040	-.527
30	+.055	-.715
30	+.070	-.898

single analysis of variance. Additionally, it was desired to decompose image size rate into two independent variables - direction and absolute magnitude - to determine if direction per se influenced performance. This required that the zero rate data be analyzed separately. Accordingly, three analyses of variance were performed on subsets of the data as depicted in Fig. 17.

The results of the analysis of variance of data set 1 are shown in Table 11. As was expected, the effect of rate of change of image size is significant at the .01 level. No other main effects were found to be significant but the interactions of direction by rate and the four-way interaction of reticle, range, direction, and rate are both significant at the .05 level. The interaction of direction and rate is shown in Fig. 18. The interaction is due to the fact that the error rate is reduced for an image rate of +.001 in/sec relative to +.006. The four way interaction was found to be due to the fact that this effect does not occur for the cross-hatch reticle and 20 ft range condition. It is found, however, for the remaining reticle-range combinations. It seems likely that the cause of this effect is the line spacing of the reticles. For very low rates, detection of motion would be enhanced if the target edge were to cross a reticle line. Since the proximity of a target edge to a line is influenced by the image size/reticle geometry configuration, local maxima and minima might well be found for various range/reticle combinations.

The finding of no significant main effect of range or direction suggests that rate of change of image size is a sufficient metric to use in predicting motion detection performance. For the levels of independent variables studied here, the data may be generalized via calculation of image size rate of change since performance appears relatively insensitive to



<u>DATA SET</u>	<u>CONSTANT PARAMETERS</u>	<u>INDEPENDENT VARIABLES (EXCLUDING SUBJECTS)</u>
1		Reticle Types Image Size Direction of Change Image Size Change Rate Initial Range
2	No Reticle	Image Size Direction of Change Image Size Change Rate Initial Range
3	No Change in Image Size	Reticle Types vs. No Reticle Initial Range

FIGURE 17. Subsets of Data Analyzed

TABLE 11. Analysis of Variance of Probability of Error - Data Set 1

<u>SOURCE</u>		<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Reticle	(A)	1	.5000	.5000	7.62
Range	(R)	1	.5000	.5000	5.92
Direction	(D)	1	.2450	.2450	<1.00
Rate	(V)	4	10.0825	2.5206	44.53**
Subjects	(S)	4	.2825	.0706	--
AxR		1	.0000	.0000	<1.00
AxD		1	.0450	.0450	<1.00
AxV		4	.2125	.0531	<1.00
AxS		4	.2625	.0656	--
RxD		1	.1250	.1250	1.29
RxV		4	.0625	.0156	<1.00
RxS		4	.3375	.0844	--
DxV		4	.9425	.2356	3.37*
DxS		4	6.9425	1.7356	--
VxS		16	.9050	.0566	--
AxRxR		1	.0050	.0050	<1.00
AxRxV		4	.2125	.0531	<1.00
AxRxS		4	.6375	.1594	--
AxDxV		4	.5425	.1356	1.56
AxDxS		4	.8925	.2231	--
AxVxS		16	1.6500	.1031	--
RxDxV		4	.2125	.0531	<1.00
RxDxS		4	.3875	.0969	--
RxVxS		16	1.3500	.0844	--
DxVxS		16	1.1200	.0700	--
AxRxRxV		4	.7325	.1831	4.02*
AxRxRxS		4	.1575	.0394	--
AxRxVxS		16	1.2570	.0786	--
AxDxVxS		16	1.3950	.0872	--
RxDxVxS		16	1.2750	.0797	--
AxRxRxVxS		16	.7300	.0456	--
TOTAL		199	34.0020		

\*  $\alpha = .05$ \*\*  $\alpha = .01$

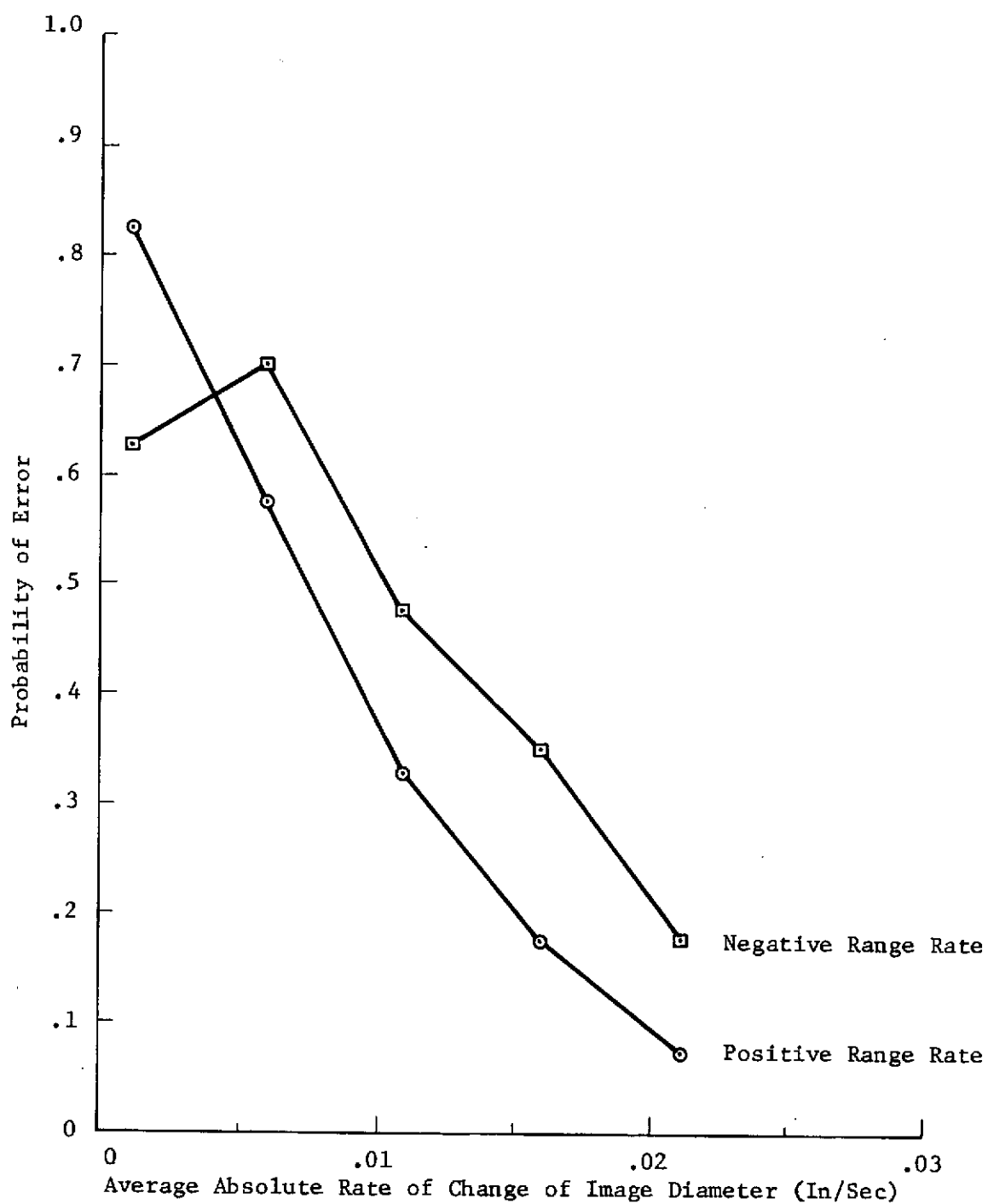


FIGURE 18. Probability of Motion Detection Error as a Function of Direction and Absolute Rate of Change of Image Diameter - Reticule Condition

direction of change or range value other than through the effects of these variables on image rate.

The results of the analysis of variance of data set 2 are shown in Table 12. The data show trends similar to those under the reticle conditions. The main effect of image rate and the direction by rate interaction are found to be significant. These effects are depicted in Fig. 19. With no reticle available, it may be seen that positive range rates are more readily detected than are negative rates for the lower rates employed in the study.

To generalize the data, it is necessary to obtain a psychometric function relating probability of detection to rate of change of image size. Since no significant effect of reticle type is shown in Table 11, the data from the two reticles were pooled. Contrasted to this, the main effect of image rate with no reticle was tabulated. Absolute image rate was employed to simplify the analysis. While certain effects of direction of motion have been located, they are of small magnitude in the case of a reticle being used. For the no reticle condition, averaging data over direction will produce predictions of performance which overshoot performance for low negative range rates and which underestimate performance for low positive rates. Since the operator must deal with both directions of motion during RMS docking operations, the general level of performance predicted should be valid. The reticle and no reticle detection functions are shown in Fig. 20. Since it is generally accepted that such psychometric functions assume a sigmoid form approximating the normal integral, theoretical functions having this form were fitted to the data. The probability of detection is given by:

TABLE 12. Analysis of Variance of Error Probability - Data Set 2

<u>SOURCE</u>		<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Range	(R)	1	.0100	.0100	<1.00
Direction	(D)	1	.3600	.3600	3.27
Rate	(V)	4	6.4600	1.6150	20.84**
Subjects	(S)	4	.2100	.0525	--
RxD		1	.0100	.0100	<1.000
RxV		4	.2400	.0600	<1.000
RxS		4	.1400	.0350	--
DxV		4	.6400	.1600	4.57*
DxS		4	.4400	.1100	--
VxS		16	1.2400	.0775	--
RxDxV		4	.0400	.0100	<1.000
RxDxS		4	.3900	.0975	--
RxVxS		16	1.1100	.0694	--
DxVxS		16	.5600	.0350	--
RxDxVxS		16	.8100	.0506	--
TOTAL		99	12.66		

\*  $\alpha < .05$ \*\*  $\alpha < .01$

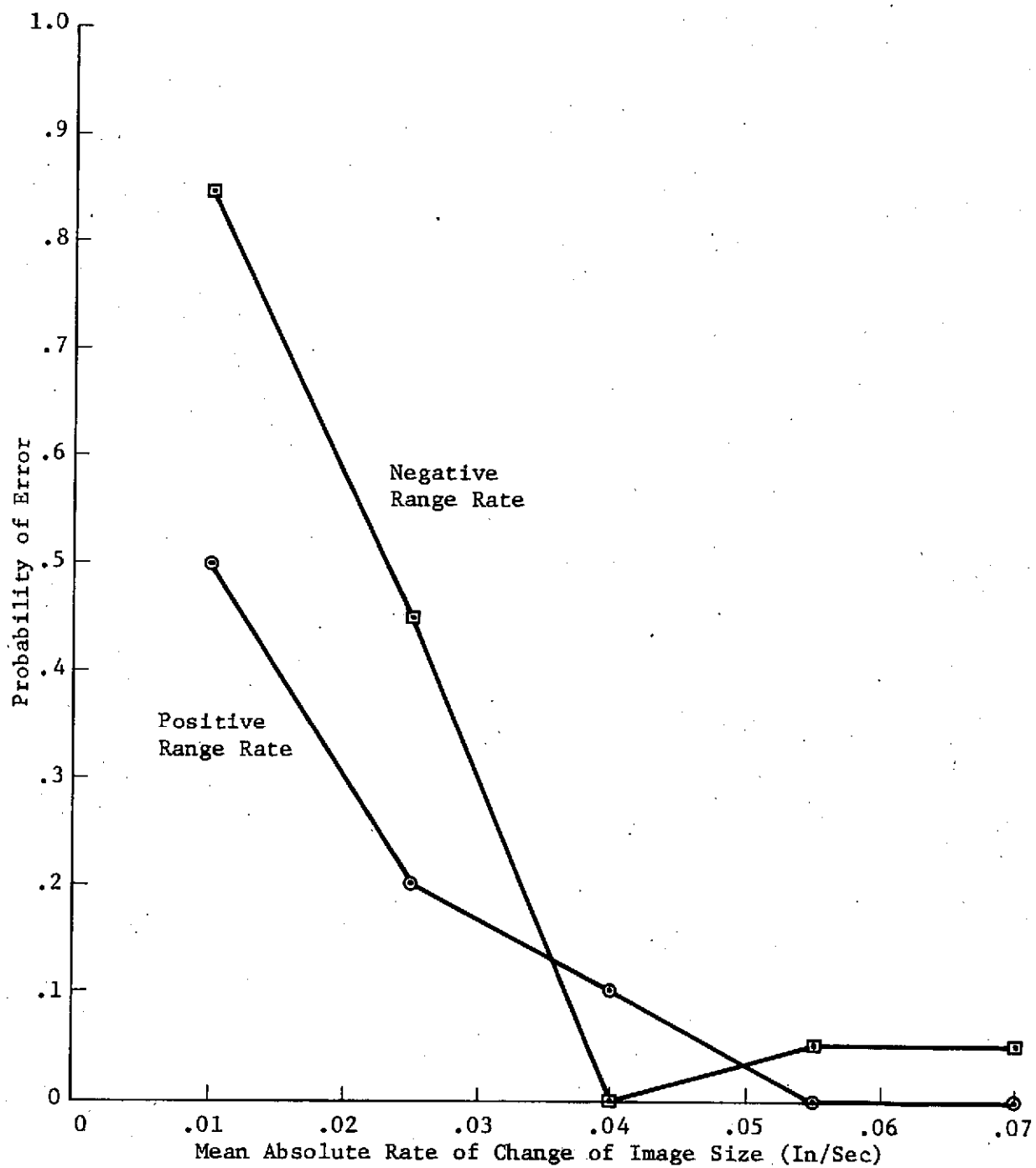


FIGURE 19. Probability of Motion Detection Error as a Function of Direction and Absolute Rate of Change of Image Diameter - No Reticle Condition

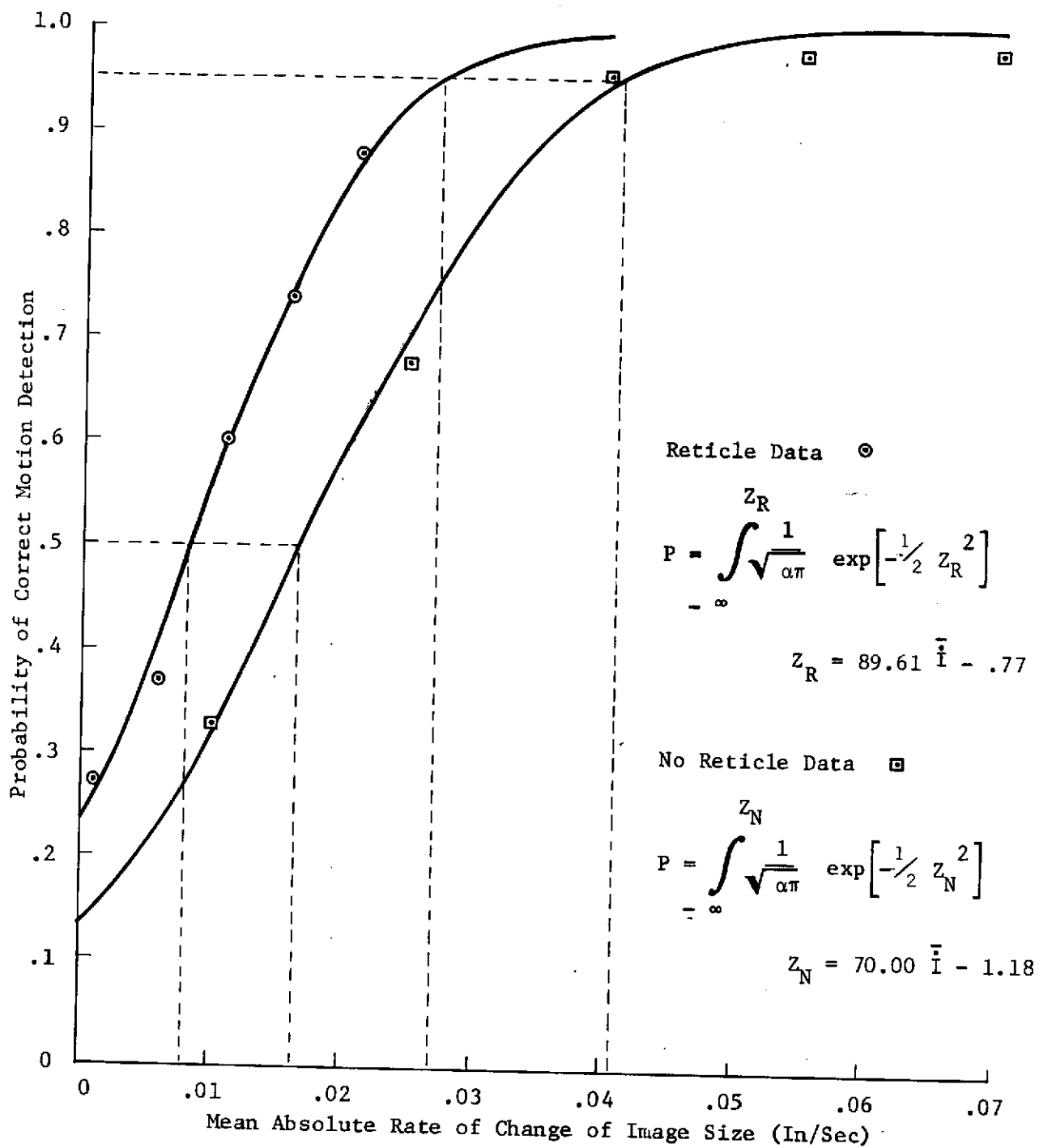


FIGURE 20. Psychometric Functions for Reticle and No Reticle Conditions

$$P = \int_{-\infty}^Z \frac{1}{\sqrt{2\pi}} \exp \left[ -\frac{1}{2} Z^2 \right] \quad (7)$$

Where Z is a standard normal deviate. The relation between Z and  $\bar{I}$  for reticle and non-reticle conditions was estimated from the data by the method of least squares with the result for reticle and non-reticle conditions respectively:

$$\begin{aligned} Z_R &= 89.61 \bar{I} - .77 \\ Z_N &= 70.00 \bar{I} - 1.18 \end{aligned} \quad (8)$$

The image rates required for .50 and .95 detection probabilities are shown in Fig.20 and the exact values calculated from the fitted functions are shown in Table 13.

Using equation (5) to generalize the results, for probability of range rate detection and use of a reticle:

$$|\bar{I}_D| = \frac{KT|\dot{R}|}{R^2} \quad (9)$$

$$|\dot{R}_D| = |\bar{I}| \cdot R^2 \cdot \left[ \frac{2 \text{ TAN } \alpha/2}{M \cdot T} \right] \quad (10)$$

To illustrate the use of eq. (10) consider the original test conditions where:

$$\frac{T \cdot M}{2 \text{ TAN } (\alpha/2)} = 65.928 \text{ in} \cdot \text{ft}$$

TABLE 13. Calculated Rates of Change of Image Diameter for Detection  
Probabilities of .50 and .90

<u>RETICLE CONDITION</u>	<u>DETECTION PROBABILITY</u>	<u>ABSOLUTE VALUE OF <math>\dot{I}</math></u>
Reticle	.50	.0086
Reticle	.95	.0270
No Reticle	.50	.0169
No Reticle	.95	.0404

Then the detectable range rate  $|\dot{R}_D|$  for .50 and .95 detection probability is given by:

$$|\dot{R}_{.50}| = .0086 \cdot .0152 \cdot R^2 \quad (11)$$

$$|\dot{R}_{.95}| = .0270 \cdot .0152 \cdot R^2$$

These functions are shown in Figure 21. In general, eq. (10) may be used to determine system parameter levels required for detection of a specified range rate using critical  $\bar{I}$  values for the desired detection probability according to eq. (7). It should be noted that the results presented were derived under stated conditions of resolution, signal-to-noise ratio, contrast, etc. and that generalizing the results to other levels of these variables is not warranted without further experimentation.

The analysis of variance table for data set 3 using zero motion rates is shown as Table 14. None of the independent variables was found to exert a significant effect on error probability. The general level of error rate for the zero motion rate case was found to be .433. This is considerably higher than the value obtained as the y-intercept of the functions in Fig. 5 which are in the range of .12 to .24. Interpreting the y-intercept as the guessing parameter for rate detection is not supported by the zero motion rate data. Evidently, a more complex decision process is operative - one which would require considerably more complex experiments to elucidate it.

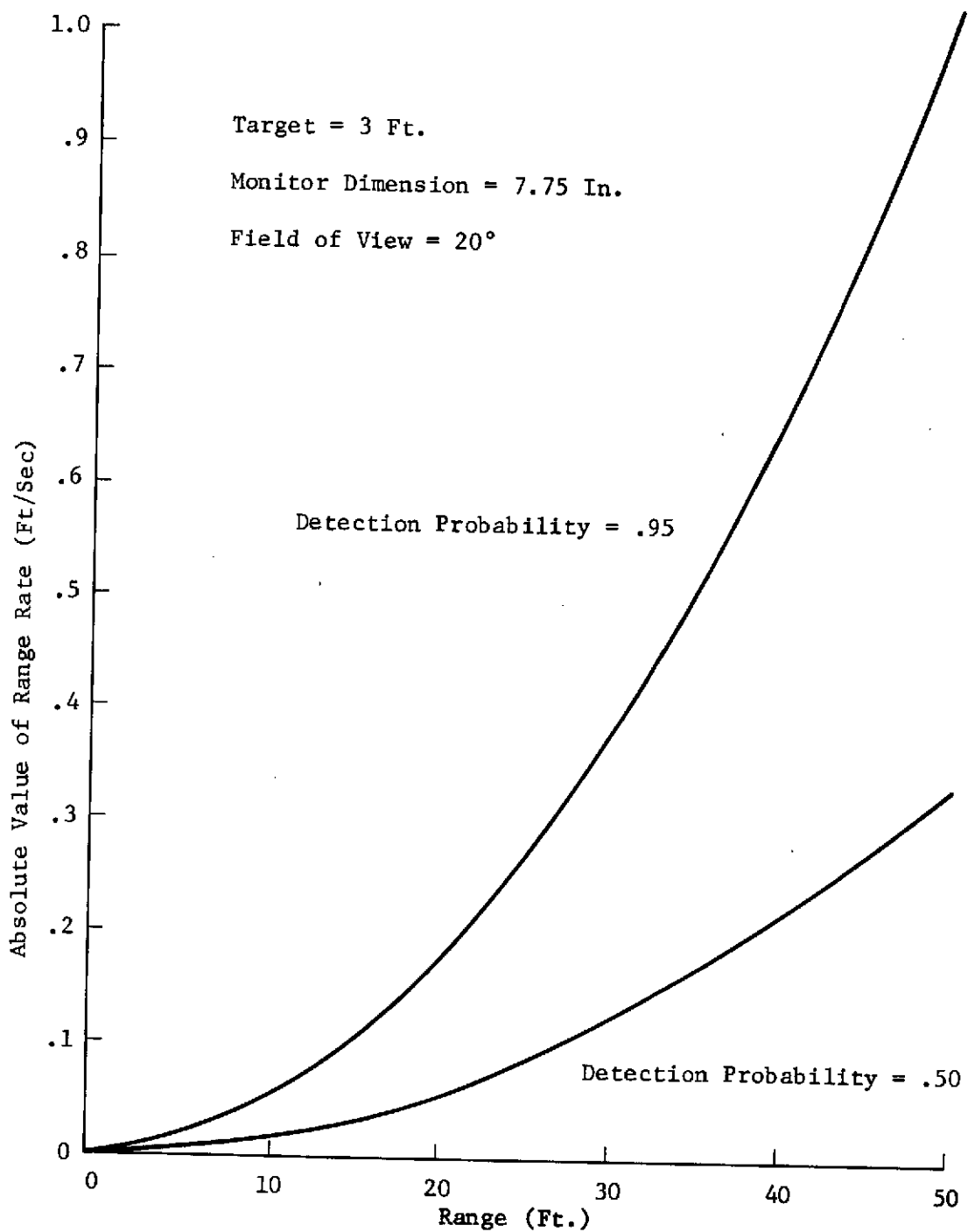


FIGURE 21. Range Rate Required for Stated Probability of Motion Detection as a Function of Range

TABLE 14. Analysis of Variance of Probability of Error - Data Set 3

<u>SOURCE</u>		<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Reticle	(A)	2	.267	.134	1.457
Range	(R)	1	.034	.034	1.030
Subjects	(S)	4	.867	.217	---
AxR		2	.266	.133	<1.000
AxS		8	.733	.092	---
RxS		4	.133	.033	---
AxRxS		<u>8</u>	<u>2.067</u>	.258	---
TOTAL		29	4.367		

## APPENDIX D

### CRT INSTRUCTIONS

THE PURPOSE OF THIS EXPERIMENT IS TO HAVE YOU READ BACK TO ME LETTERS AND NUMBERS I WILL SHOW YOU ON THIS TV.

(PAUSE)

I AM GOING TO SHOW YOU 12 CHARACTERS AT A TIME, ARRANGED IN A 3 (E gestures horizontally across TV screen) BY 4 (E gestures vertically down TV screen) BOX. YOU WILL START READING THE LETTERS AND NUMBERS IN THE UPPER LEFT CORNER (point to the corner) AND PROCEED TO THE RIGHT, READING THE THREE CHARACTERS IN THE FIRST ROW AND THEN GOING DOWN TO THE SECOND. (Pause) IN OTHER WORDS, YOU WILL READ THE ALPHA AND NUMERIC CHARACTERS OUTLOUD, IN THE SAME ORDER YOU WOULD NORMALLY READ THE PAGE OF A BOOK.

DO YOU HAVE ANY QUESTIONS?

(PAUSE)

WHEN YOU HAVE READ ALL 12 CHARACTERS, YOU WILL PUSH THIS POINTING BUTTON (E depresses response key) AND THIS WILL REMOVE YOUR TV PICTURE. YOU WILL HAVE 60 SECONDS TO READ ALL 12 CHARACTERS. IF FOR SOME REASON YOU ARE NOT ABLE TO READ ALL 12 CHARACTERS IN THE 60 SECONDS, THE PICTURE WILL AUTOMATICALLY BE TERMINATED. HOWEVER, THE IDEA IS TO READ AS MANY OF THE 12 CHARACTERS AS POSSIBLE. IF IT IS IMPOSSIBLE FOR YOU TO MAKE OUT SPECIFIC CHARACTERS, JUST SAY: "CAN'T TELL" AND GO TO THE NEXT CHARACTER.

ANY QUESTIONS?

I WILL BE ADJUSTING THE SCENE YOU SEE BETWEEN TEST TRIALS, SO YOU WILL NOTICE THE PICTURE QUALITY AND THE TYPES OF LETTERS AND NUMBERS CHANGING. IF, HOWEVER, YOU HAVE UNPLANNED DIFFICULTY WITH YOUR TV DISPLAY-SUCH AS "FLOPPING OR ROLL" OF THE PICTURE, PLEASE CALL ME IMMEDIATELY.

IF THERE ARE NO QUESTIONS, WE WILL BEGIN: . . . . .